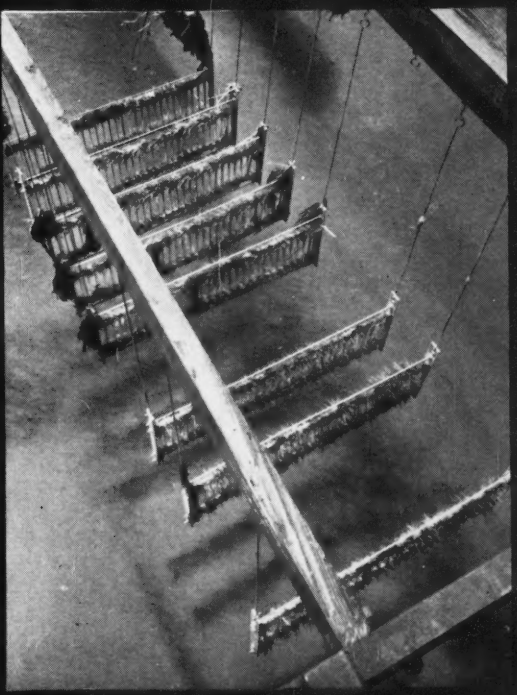
Corrosion



December 1945

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When considering the installation of Cathodic Protection for pipelines, it is important to select a pipe protection whose underground electrical insulating properties are not affected by varying moisture content of the soil during changes in season, weather or by time itself. Obviously, the correct amount of electrical current cannot be varied continually to compensate for the fluctuations in current required.

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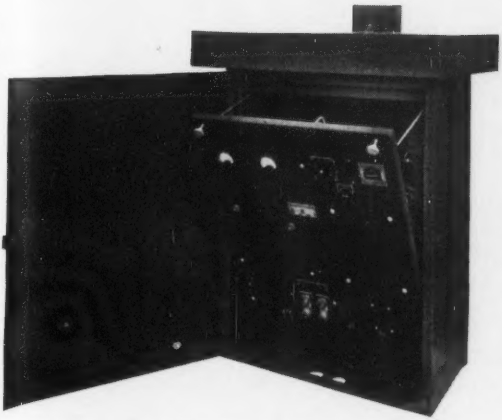

Above illustration shows enclosure door open, with instrument panel tilted forward for inspection.

- Cathodic Protection Rectifiers have "Selenium" rectifier stacks.
- Available for use on single phase or 3 phase A.C. Power.
- Available - self cooled, fan cooled or air cooled.
- Available in all D.C. voltages and current outputs desired.
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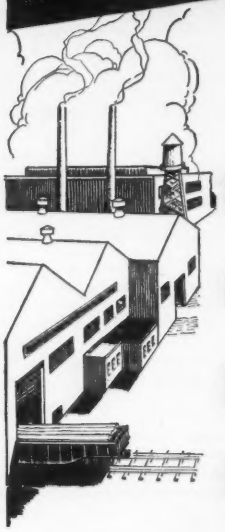

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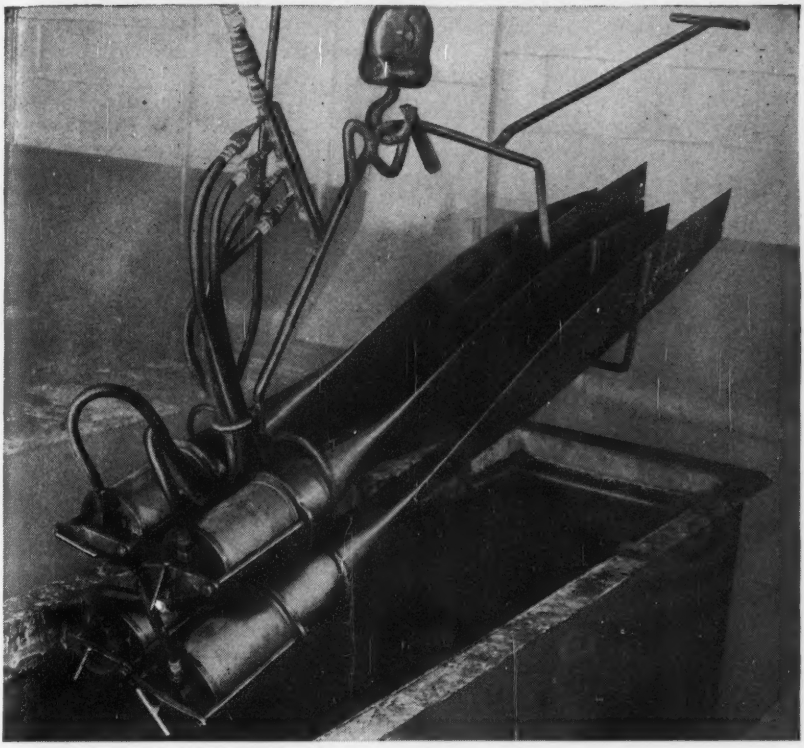

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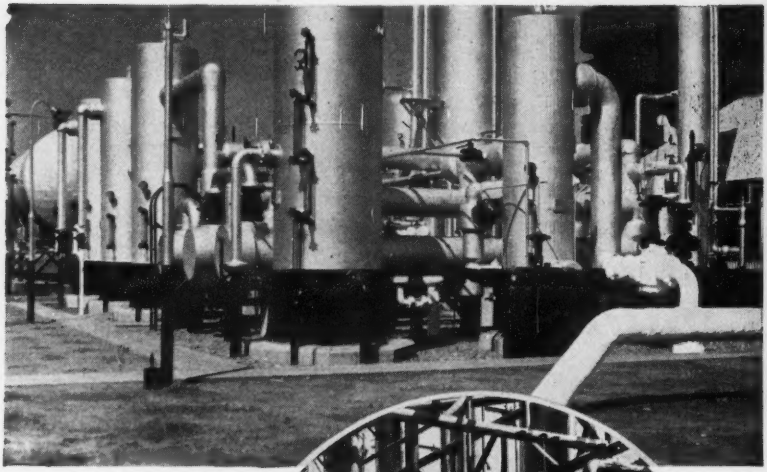

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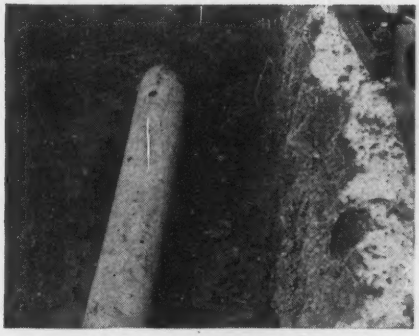
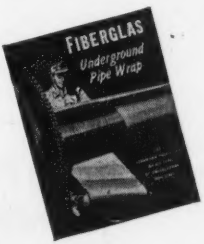


● **Above: Section of underground pipe, covered with Fiberglas Mat, after five years of service. Volatile oils were still preserved in the coating, indicating many more years of service are available.**

● **Below: Fiberglas Underground Pipe Wrap is easy to handle. The flexibility and strength of Fiberglas Mat permit easy application with conventional wrapping equipment.**



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Pioneers in the manufacture and application of asbestos wrappings . . . Johns-Manville has gone a step further with this new machine.

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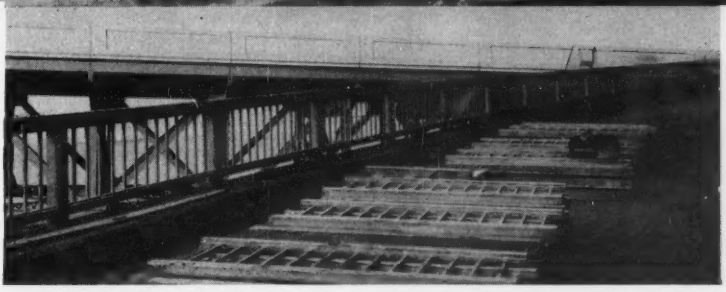

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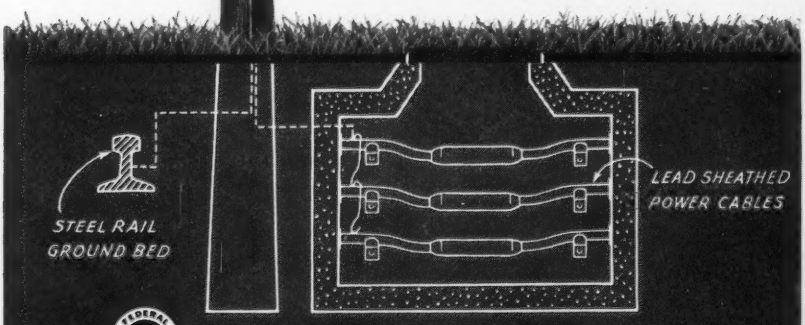

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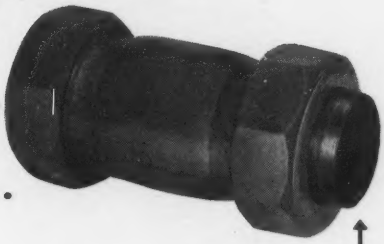

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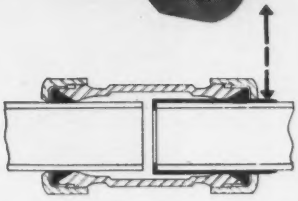

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—available with insulating gaskets or Armored Gaskets.

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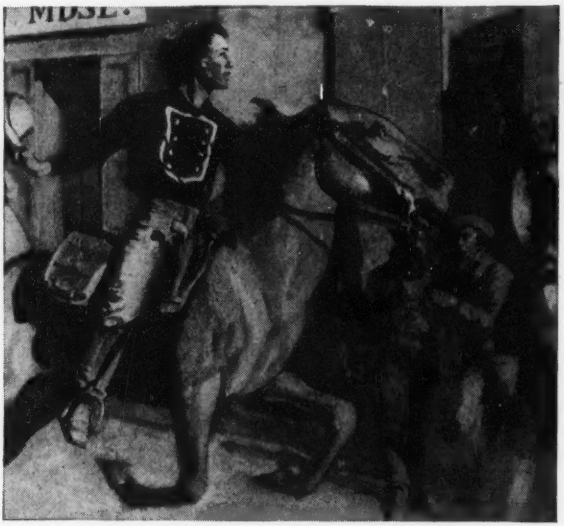

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The first Pony Express started from both Sacramento, California, and St. Joseph, Missouri, 1,960 miles apart, at 5 p.m. on April 3, 1860. There were 80 riders and 420 horses. Riders changed ponies at relay stations 10 miles apart and the distance was covered in 8 to 10 days. Letters were carried for $5.00 each until the service ended in October, 1861.

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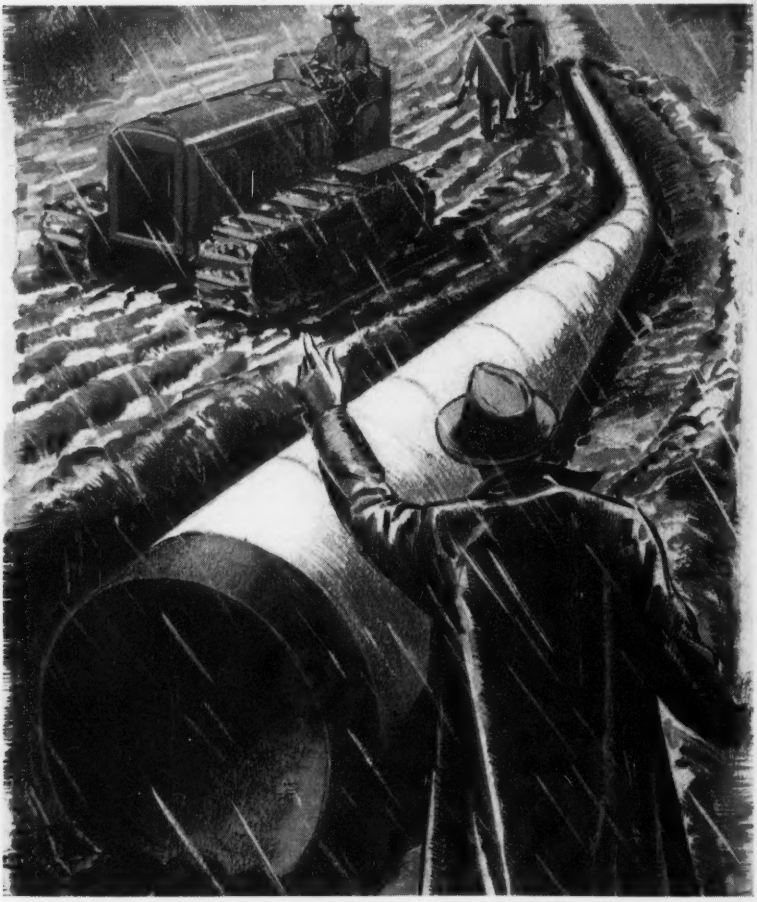

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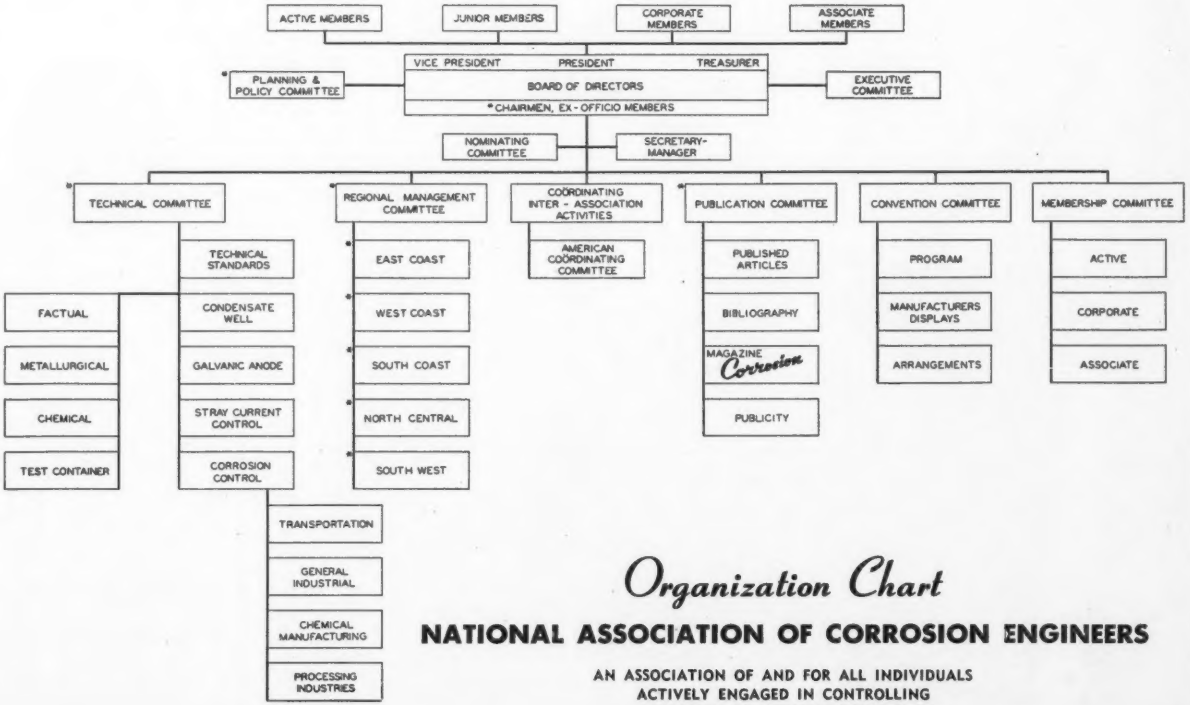
EXPORT: THE ARMCO INTERNATIONAL CORPORATION

ARMCO

ARMCO STEEL PIPE



Organization Chart

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

AN ASSOCIATION OF AND FOR ALL INDIVIDUALS
ACTIVELY ENGAGED IN CONTROLLING
CORROSION OF METALLIC STRUCTURES

Corrosion

An Official Publication of the

NATIONAL ASSOCIATION OF CORROSION ENGINEERS

ELTON STERRETT, Executive Secretary

A quarterly publication—to provide in permanent record the papers prepared for the Association, at meetings, annual conventions and from editorial sources.

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NATIONAL ASSOCIATION OF
CORROSION ENGINEERS

Volume 1 DECEMBER, 1945 Number 4

Contents

Electrolysis Surveys on Underground Cables, By L. J. Gorman....163

Marine Corrosion Testing Station at Kure Beach, N. C.....178

The Behavior of Zinc-Iron Couples in Carbonate Soil, By T. H. Gilbert and Guy Corfield.....187

Control of Pipe-Line Corrosion—A Manual, Part I, By O. C. Mudd.....192

Corrosion Protection by Phosphatization, By Michael A. Streicher.....219

Notes on Use of Copper-Nickel Alloy in HF Alkylation Processes, By B. B. Morton.....228

N.A.C.E. Organization Chart..... 18

Corrosion Abstracts..... 21

Geographical Roster of N.A.C.E. Membership..... 38

Index to Advertisers..... 46

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Electrolysis Surveys on Underground Cables

By L. J. Gorman
Consolidated Edison Company of New York, Inc.

THE CONTROL of electrolytic corrosion on an underground cable system requires an adequate supervision of the various factors causing corrosion and the maintenance of the measures adopted for its mitigation. The supervision and maintenance are accomplished through surveys and tests systematically planned to check periodically the conditions existing on the system and to obtain the information required for the application of corrective measures. The test methods used are of primary importance and must yield data that will correlate with the actual corrosion experienced.

This paper presents a summary of the test methods and practices which are the outgrowth of long experience with electrolysis and corrosion on the power system cables of the Consolidated Edison Company of New York, Inc. The system comprises approximately 22,000 miles of underground lead-covered cable operated in cable ducts and subject to a wide variety of soil and duct conditions.

The principal causes of corrosion are identified as 1, direct chemical attach, 2 stray current electrolysis, 3 galvanic attack between the lead sheath and other metals, and 4 electrolytic cell corrosion resulting from environmental conditions. Approximately 65 percent of the corrosion experienced on the system is attributed to the various environmental types of electrolytic cell. Stray current electrolysis has been reduced to minor proportions through the coöperative efforts of the several electric transit systems and the cable and pipe operating utilities concerned. However, the stray current problem still exists, potentially, and its control must be exercised through the continued supervision and maintenance of the various measures that have been installed for electrolysis mitigation.

A detailed discussion of the electrolysis conditions affecting the Consolidated Edison System and the various methods adopted for the control of corrosion are presented in a recent paper by the author (1). The following is a description of the survey methods and the methods for analyzing the electrolysis test data to evaluate the severity of corrosion conditions.

Electrolysis Surveys and Tests

The electrolysis surveys and tests may be grouped into three general categories, namely: 1, Maintenance Surveys, 2, General Surveys and 3, Special Investigations.

The "Maintenance Surveys" are made at selected locations on the system to check the existing electrolysis conditions, and to detect any new conditions resulting from operational changes in the electric transit systems or as a result of al-

terations or extensions to the cable system. The test locations include all railway drainage connections, bonds to foreign cable systems, cathodic protection installations, as well as other key points on the system. Usually, the maintenance tests are scheduled on an annual basis. Some installations such as those involving drainage switches, rectifiers and other special equipment are inspected more frequently. In other cases, where the conditions are well stabilized, an inspection every two or three years is sufficient.

The "General Electrolysis Surveys" are made for the purpose of locating corrosion areas and to obtain general information on the electrolysis conditions affecting the system. Where required, the general surveys are supplemented by special tests to determine the protective measures to be installed in areas subject to electrolysis and corrosion. The surveys are planned to cover systematically the various parts into which the system is divided for the purpose of the survey. Particular consideration is given to localities in which changes in the electrolysis conditions are likely as the result of changes in the electric transit lines or to important modifications in the cable systems.

"Special Investigations" are made in situations where a more or less extended investigation is required. Frequently they involve the underground structures of other companies and may be initiated by either company depending on what structures are involved. The special work includes the investigation of the conditions incidental to corrosion failures and the surveys and tests made in connection with important new cable installations.

Test Methods

The test methods employed for stray current electrolysis surveys have been fairly well standardized and the test procedures are described in detail in the various publications on that subject (2), (3). In situations involving only stray current, the standard procedures continue to give satisfactory results. However, the usual stray current electrolysis tests do not yield information on the local electrolytic cell conditions existing between the test points because of the wide variations in the soil and duct conditions from point to point along the cable ducts. For this reason, other test methods are required for the electrolytic cell types of corrosion.

In the early 1930's it was found that the usual manhole tests did not give information on the electrolysis conditions in certain localities where severe cable sheath corrosion was experienced and where the corrosion could not be accounted for by stray current. Accordingly, considerable experimental work was done to develop a test method that would yield test data that could be correlated with actual cable sheath corrosion. This work has resulted in the duct survey.

During the past ten or twelve years, the duct survey has been used extensively to explore the electrolysis conditions existing in duct sections between manholes, and particularly to investigate the duct conditions incidental to corrosion failures. The duct survey is also used to advantage where it is desired to explore the electrolysis conditions in

ducts prior to the installation of new cable. Furthermore, statistical studies have been made of a considerable number of duct survey data, obtained in connection with actual cable failures, to establish a correlation between the test data and corrosion and to obtain information which can be used as a basis for estimating the severity of particular electrolysis situations. The duct survey is now standard practice on the cable system of the Consolidated Edison Company.

The Duct Survey

The duct survey is made by pulling an electrode through a vacant duct which is adjacent to the ducts carrying cable. Instruments are connected between this electrode and the lead sheath of the adjacent cables as shown in Figure 1. Measurements of potential, current and resistance are made at frequent intervals (5 to 10 feet) throughout the duct. The duct selected for the survey should be as near to the cables as possible and should be one of the lower ducts so as to obtain the most severe conditions. Where the cable is removed because of cable failure, it is desirable to survey the duct before new cable is installed.

The test electrode most generally used consists of a piece of cable 12 inches long and 2.75 inches in diameter fitted with a pulling eye and test leads. Although various non-polarizing and other special types of electrode have been investigated, the most satisfactory results from the standpoint of field conditions have been obtained with the short length of lead cable sheath. The essential requirement is that the electrode be as simple and as rugged as possible. A small galvanic potential may exist between the cable sheaths and the test electrode although the material in both is the same. However, this difference is small (0.01 volts or less) and does not seriously affect the results. The surface of the electrode should be maintained in good condition and its electrode potential with respect to the cable sheath should be checked periodically using manhole or duct water as the electrolyte.

The potential between the cable sheath and the duct wall is measured by the voltmeter connection shown in Figure 1. A high resistance voltmeter or potentiometer should be used so as to minimize the errors due to electrode contact resistance. Voltmeters having a resistance of 400,000 ohms or more per volt are satisfactory for this purpose and are more convenient than the potentiometer. Because of the high resistance in the voltmeter circuit the potential of the test electrode is substantially that of the duct wall with which it is in contact. The measurement thus obtained is a close approximation of the potential of the cable sheath in the occupied ducts with respect to the duct wall from point to point throughout the duct. The indicating voltmeter measurements are supplemented by a time record of the potential, taken at a selected point in the duct, to determine the characteristics of the duct potential. A 24-hour recorder having a resistance of 10,000 ohms per volt is used for this purpose. The characteristic of the record will indicate whether the conditions are due to an external source of potential, such as stray current electrolysis, or to an electrolytic cell condi-

tion set up by variations in the environment. Stray current potentials will show the usual railway characteristics whereas the electrolytic cell potentials will have a steady characteristic with values slightly decreasing in magnitude as the result of polarization. In some cases both the railway and the electrolytic cell characteristics will be shown superimposed on the same record.

The cable sheath corrosion is proportional to the magnitude and density of the current discharge from the cable sheath to the duct wall. This discharge of current can be estimated from point to point through the duct by bonding the test electrode to the cable sheath through a low resistance milliammeter. Since the resistance of the milliammeter circuit is relatively low, the potential of the test electrode, in this case, will be substantially that of the cable sheath and it may be assumed that the current discharge per foot of cable at the point of test is approximately in the same order of magnitude as that measured through the test electrode. This current, when flowing into the duct wall, will cause anodic corrosion and when flowing to the cable sheath it may result in cathodic corrosion.

In the measurement of potential and current, it is important to correct for the I R. drop due to any stray current flowing on the cable

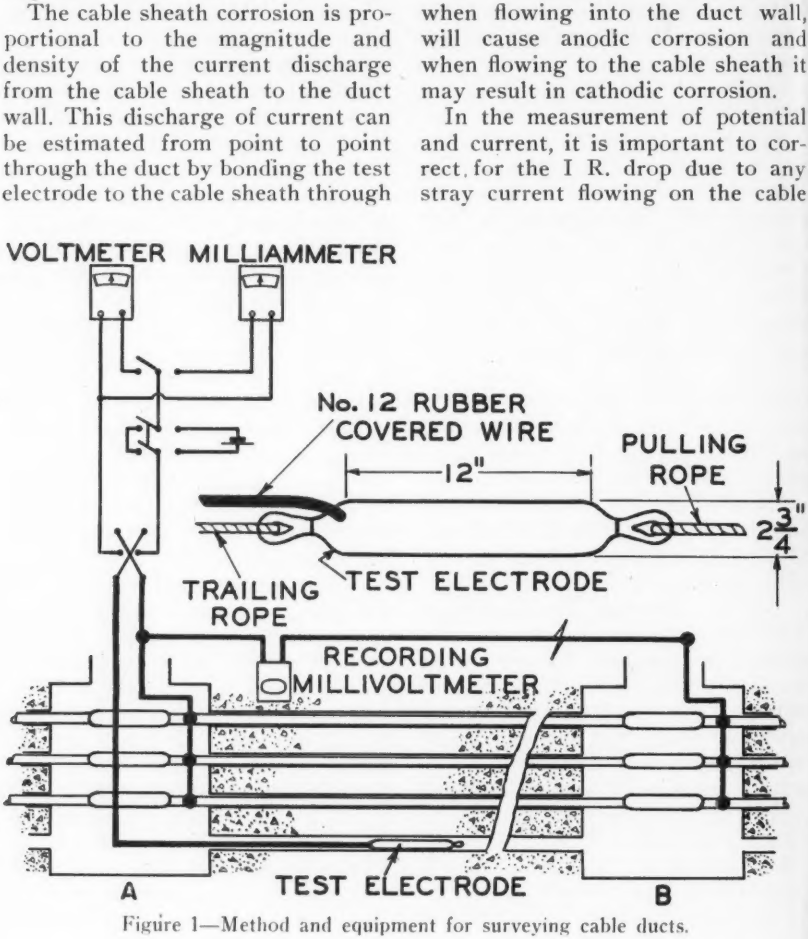


Figure 1—Method and equipment for surveying cable ducts.

sheath. Where the cables are carrying appreciable stray current, say from manhole A to manhole B, Figure 1, there will be a potential drop along the sheath and a reading taken at some mid position in the duct and referred to the sheath in manhole A will not give the correct values for the potential and current at the point of test. To correct for sheath current the usual practice is to record the magnitude and direction of the current flowing on the sheath and to compute the I R. drop to the point of test. The appropriate correction is then applied to the readings of the potential and a corresponding correction is made in the current measurement. Where it is desired, the I R. drop over the section of cable under test can be measured directly from manhole to manhole by a millivolt recorder, as shown in Figure 1.

The duct resistance is an essential factor in determining the magnitude of current under any given duct potential. The resistance between the test electrode as one terminal and the adjacent cable sheath as the other is measured at each test point by connecting a low voltage battery (1.5 volt dry cell) in series with a sensitive milliammeter between the cable sheath and the test electrode. The resistance is computed from the battery voltage and the measured current. The milliammeter used for this purpose should have a sensitivity in the order of 0.05 milliampere per division and its resistance should not exceed 2 or 3 ohms. With suitable shunt resistance the range of the milliammeter can be varied to any desired value and the same instrument can be used for both the current and the resistance measurements through the switch connections shown in Figure 1. A reversing switch is required in the battery circuit so as to reverse the potential on the test electrode to minimize any errors due to small d. c. sheath potentials, polarization, or other effects. The battery current in this test is usually small and does not appreciably influence the battery voltage. However, it is good practice to check this voltage from time to time during the progress of the survey. Other methods for measuring the duct resistance have been used. However, the method described above has given the most satisfactory results.

The duct resistance as measured in the foregoing is somewhat arbitrary and is mostly the contact resistance between the surface of the electrode in contact with the duct wall and represents, approximately, the contact resistance per duct foot of cable when the duct is occupied. The area of contact will vary, depending on the duct conditions. In dry ducts the contact area will be small. In ducts containing mud and water the contact may be an appreciable part of their total electrode area. The resistance of the duct bank, the earth and the contact resistance between the duct walls and the cable sheath in the occupied ducts are also included in the resistance measurement. However, these resistances are relatively low compared to the electrode resistance and apparently do not appreciably influence the test results. The relation between contact area and resistance and its influence on the interpretation of the test data is discussed in a following section.

In new installations where it is

desired to explore the duct conditions prior to installing cable or where existing cables are not available in the duct bank under test, the adjacent water pipe or other pipe or cable system can be used for a resistance survey. In such a survey the potential and current measurement, if made, will have no very significant meaning. However, the resistance measurements will give fair indication of the duct conditions and will aid very materially in determining where protective measures should be taken.

Under the usual conditions it must be realized that there are numerous points throughout the cable duct where the sheath is subject to small local potentials due to such causes as differential aeration, concentration cells, etc. With the cable in place these potentials are not accessible for measurement, and if the cable is removed the original condition no longer exists. However, the existence of a potential must be assumed. The potentials concerned in this category are local in character and are usually small, but in aggravated cases they may be in the order of 0.1 volt or more. In general, it must be assumed that these local potentials exist to a greater or less extent in all ducts containing cable. Their effectiveness in causing sheath corrosion will depend upon the resistance of the environment in immediate contact with the cable sheath, and upon polarization and other effects resulting from the flow of current. This fact emphasizes the importance of duct resistance as a factor in cable sheath corrosion, and a factor which is very frequently overlooked in electrolysis work.

Analysis of Electrolysis Test Data

An accurate evaluation of an electrolysis condition can be obtained only through the proper analysis and interpretation of the test data. Readings of potential and current have no particular significance unless they can be translated into terms of corrosion on the cable or piping system concerned. The desired interpretation of test data can be best obtained through the systematic investigation of the conditions incidental to corrosion cases and studying the accumulated data in accordance with the appropriate statistical methods.

Electrolysis test data serve two general purposes: 1, for individual cases, they serve to identify the cause and furnish the information required for the application of suitable remedial measures to the particular case concerned; 2, when properly classified and analyzed, together with other similar data taken systematically over the system, they constitute the basis for statistical studies of the conditions existing on the system as a whole. For this reason, the systematic taking and recording of data by trained observers in accordance with a well developed plan is of first importance in making electrolysis surveys and in planning for overall improvements on the system.

The foregoing general principles have been applied in the analysis of the duct survey data with a view to showing the relationship between the data and actual cable sheath corrosion. For this purpose studies were made of the duct survey data obtained over a period of approximately four years.

The results of the duct resistance surveys made uniformly over the system are given in Figure 2. Curve A shows the duct resistance plotted on a cumulative percentage basis for approximately 9500 duct resistance tests made at random but well distributed points on the system. This curve shows, for example, that in 65 percent of the tests the duct resistance was above 1000 ohms and less than 1000 ohms in 35 percent of the tests. Curve B of the figure is a similar percentage curve of duct resistance obtained in connection with approximately 200 cable failures which were attributed to sheath corrosion. From this curve it will be noted that only 5 percent of the corrosion failures occurred in ducts having resistances of 1000 ohms or more. Further, it will be noted that 70 percent of the corrosion failures occurred in ducts in which the resistance was 250 ohms or less, whereas in Curve A only 6 percent of the total tests was under 250 ohms. These results indicate that the greater portion of the corrosion is occurring on a relatively small part of the system, that is, 70 percent of the corrosion is occurring in approximately 6 percent of the ducts. In general the curves show the importance of duct resistance as a factor in the rating of cable ducts with respect to corrosion. On the basis of the data, ducts in which resistance of 250 ohms or less are measured are rated unfavorable from the standpoint of corrosion.

For the purpose of relating test

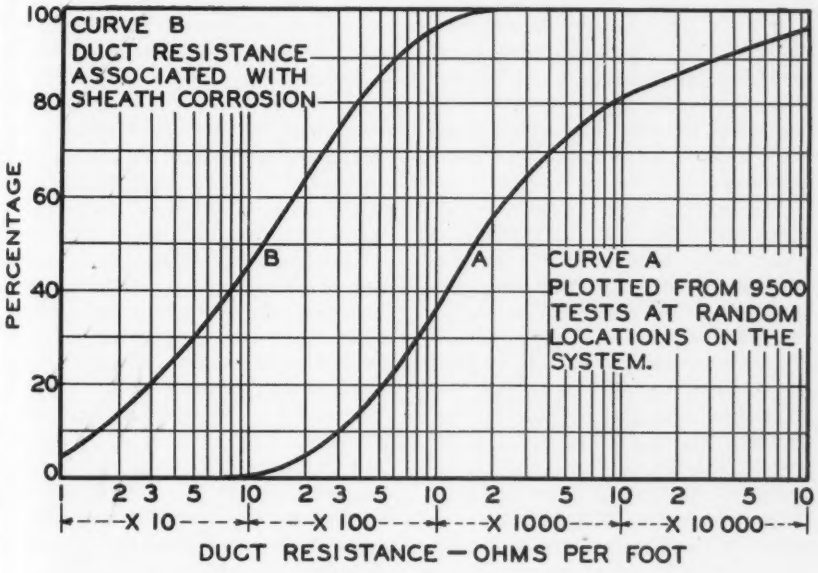


Figure 2—Cumulative Percentage Curves showing the results of duct resistance surveys.

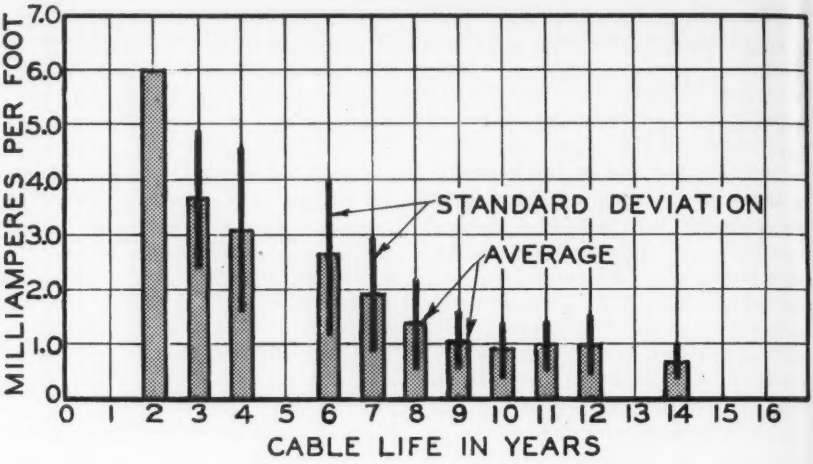


Figure 3—Age of cable versus average current discharged through test electrode. Data obtained in connection with corrosion failures.

data with actual corrosion and to establish a basis for the interpretation of the duct survey, studies were made of the potential, current and resistance data obtained in investigation of the approximately 100 corrosion failures for which complete and consistent data were obtained.

The first attempt is shown in Figure 3 in which the distribution of cable life is related to the average current discharged from the test electrode to the duct wall at or near the point of failure. For the purpose of this analysis, the cable life, from the date of installation to the date of failure, was grouped into yearly periods, that is, all failures falling within N years — 5 months and N years + 6 months were grouped under N years. The vertical columns in the figure show the averages of the currents measured for the failures occurring in each of the yearly groups from 2 to 14 years. The standard deviations from the mean value of current were computed and shown by the vertical lines associated with each of the columns.

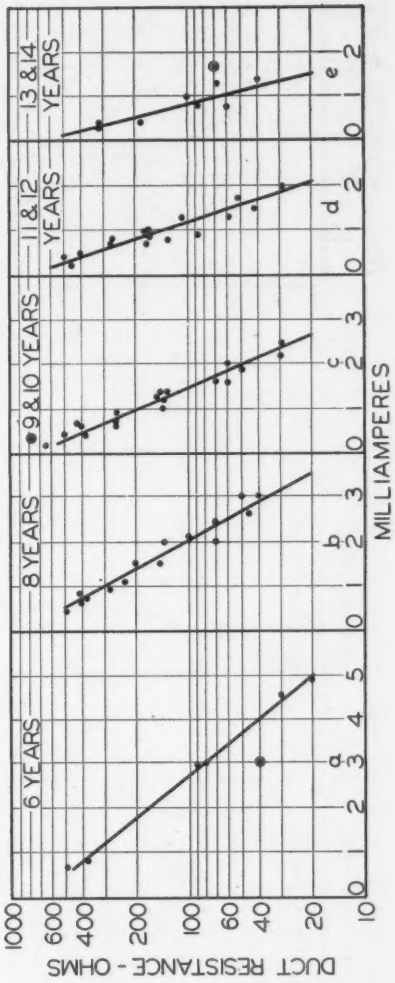
The magnitude of the deviations and other elements in the data show that the variations for any period are more than can be attributed to chance and prohibit a correlation between corrosion and the average current as measured. Furthermore, the lack of correlation is also evident from the fact that the contact area of electrode varies considerably under different duct conditions, thus introducing the question of duct resistance as a factor related to duct corrosion.

In order to incorporate duct resistance as a factor in the analysis, the data were grouped for convenience in two-year periods and the current plotted with respect to duct resistance on semi-log paper as shown in Figures 4a to 4e. A straight line

was drawn to show the best averages between current and duct resistance in each of the groups. From these figures, curves were constructed showing the relation between cable life and current for four values of duct resistance as shown by the curves in Figure 5. In comparing Figure 5 with Figure 3, it will be seen that the deviations in Figure 3 can be accounted for by variations in the duct resistance. Although there is some variation in the resistivity of the duct contents, it is believed that the duct resistance depends primarily on the area of contact. Consequently, for a given total discharge per foot of cable, the current per unit area is relatively less than in low resistance ducts because of the greater contact area; that is, one milliampere measured in a 50-ohm duct represents a much lower current density than the same current measured in a 400-ohm duct.

The relationship between cable life, discharge current and duct resistance shown in Figure 5 has been confirmed in numerous surveys made since the curves were constructed. For example, in a recent case involving an important tie feeder, the survey showed a duct resistance of approximately 500 ohms and a discharge of 0.9 milliamperes at a point where corrosion had penetrated the cable sheath. Interpolating from Figure 5, the probable life of the cable was estimated at approximately four years. The sheath of the cable was penetrated by corrosion at a second point in the same duct where the duct resistance amounted to 200 ohms. The current was 2.4 milliamperes and the estimated cable life was slightly less than four years. The feeder had

Figure 4—Electrode current versus duct resistance for cable in five age groups. The data are those used in Figure 3, but recognition is given to duct resistance.



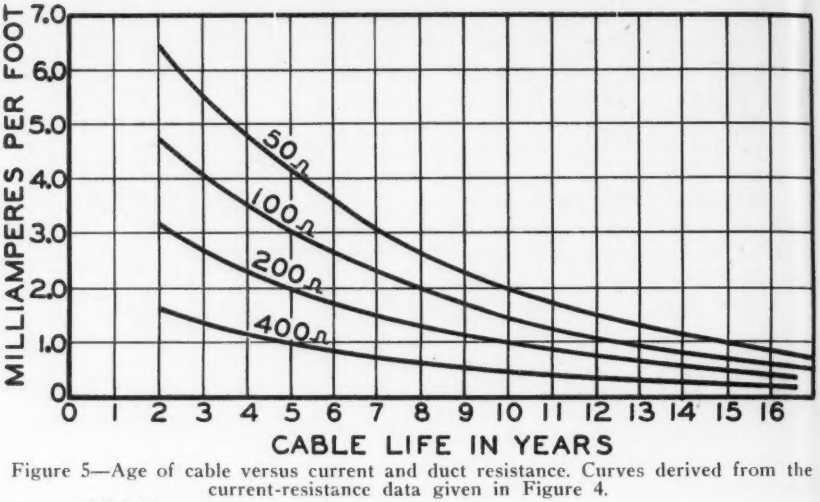


Figure 5—Age of cable versus current and duct resistance. Curves derived from the current-resistance data given in Figure 4.

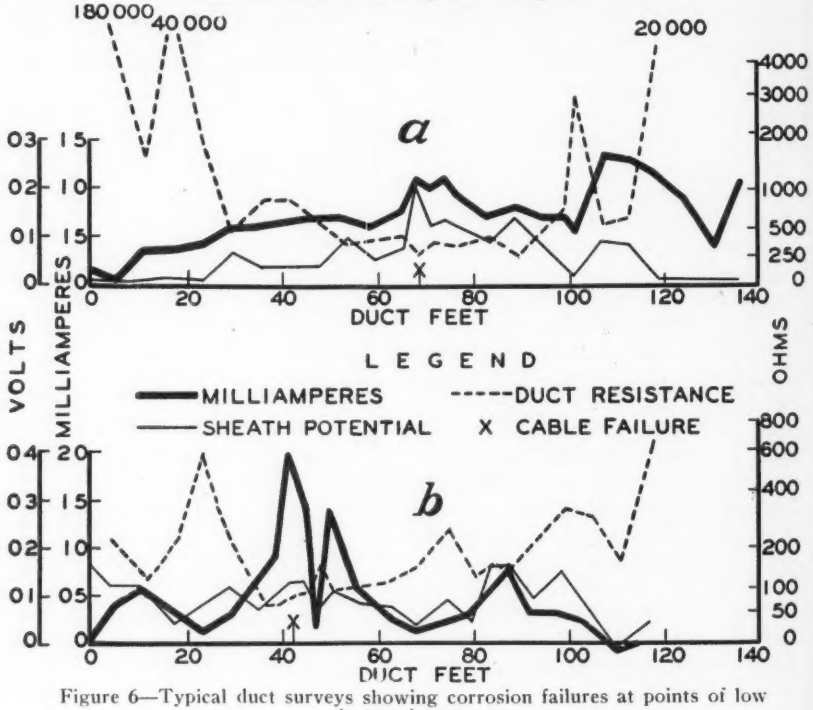


Figure 6—Typical duct surveys showing corrosion failures at points of low duct resistance.

been in service four years and two months at the time of the failure. The corrosion in this case was caused by soil potentials resulting from cinder filled soil adjacent to the duct bank. Potentials amounting to 0.7 volt were measured between the cable sheath and the duct wall. Typical duct surveys are shown in Figure 6.

Identifying the Causes of Corrosion

The procedure used for identifying the cause of corrosion in a particular case is substantially that described by Radley and Richards (4), supplemented by field tests. The severity of the corrosion and its general characteristics are determined by an inspection of the cable, from which an estimate is made as to the probable cause as follows:

(a) Steep-sided, sometimes undercut pits, long corroded furrows and inter-crystalline attack indicate anodic corrosion resulting from some form of electrolytic action, either stray current electrolysis or the electrolytic cell type of attack. Pitting closely associated with score marks, duct rubs or other mechanical damage on the sheath is usually attributed to self corrosion in a low resistance duct.

(b) A more uniform attack in which the crystal boundaries are not subjected to preferential damage, shallow saucer-like pits, or corroded patches indicate some form of a chemical attack. An examination of the corrosion products will frequently indicate the probable nature of the chemical reaction. The attack may be due to some foreign substance in the duct or may result from stray current under cathodic conditions.

The laboratory inspection outline in the foregoing is usually supplemented by a field test from which the final identification of the cause is made. Where the inspection shows electrolytic corrosion, the duct conditions are tested for: (1) stray current potentials; (2) electrolytic potentials resulting from soil conditions internal to the duct bank; and (3) duct resistance and the possibility of internal duct corrosion resulting from differential aeration or other types of local electrolytic cell. All of these electrical characteristics are determined by the duct survey.

In the case of chemical attack, a search is made of the ducts and in the immediate vicinity for any chemical condition that would account for the corrosion of the cable sheath. This usually involves a chemical analysis, including pH measurements, of the duct contents and manhole water. The condition may be due to chemicals entering the manholes or ducts from some industrial operation in the vicinity, but is more frequently caused by alkaline concentrations from the concrete in which the ducts are laid. In this connection, it should be noted that power system cables are frequently operated at considerable temperature and that water collecting in an undrained portion of the duct is slowly evaporated leaving a concentration of any salt contained in the water. Where the cable sheath is appreciably negative with respect to the duct wall, the condition is aggravated. Under such conditions, the failure is attributed to cathodic corrosion.

The foregoing procedure of in-

spection, supplemented by field tests, has given a reliable identification of the cause of corrosion in approximately 90 percent of the corrosion failures.

Cable Sheath Protection

The measures used for cable sheath protection on the Consolidated Edison System include "electrolysis drainage," "cathodic protection," "tape protected cables" and the use of a special cable grease which is applied to the cable sheath in ducts known to be corrosive.

Electrolysis Drainage—Electrolysis drainage is used extensively for the mitigation of stray current electrolysis. There are approximately 137 drainage connections on the system in which the drainage current varies from 50 amperes to 1200 or 1300 amperes at the larger substations. The total current drained from the cable system is in the order of 20,000 amperes. This drainage system has proven effective in the stray current areas and has reduced stray current corrosion to 4 or 5 percent of the total corrosion experienced on the system. Drainage, however, is not feasible in many of the areas subject to the electrolytic cell type of corrosion.

Cathodic Protection—In certain instances, where applicable, the cathodic scheme of protection is used. There are several of these installations in operation on the power cable system in New York City. In some installations the anode consists of scrap cable installed in a vacant duct with its sheath connected through a rectifier to the cables under protection. Scrap railroad rails buried adjacent to the duct bank have proven satisfactory in other installations. Where the current requirements are small, bare rail is used. In cases where considerable current is required, the rail is imbedded in coke breeze. In one of our installations a plain rail has been in service for approximately six years, discharging an average of 10 milliamperes per foot of rail.

Under the congested conditions found in New York City, the cathode method has but limited application. Where used, precaution must be taken to avoid discharging current to other structures which are not included in the protective scheme. The current discharged from individual short electrodes or from sections of a long electrode laid parallel to the cables will vary between wide limits from point to point, depending on the soil conditions. Unless the anodes are sectionalized and the supply of current to each section is controlled, there is danger of supplying too much current in some sections in order to obtain protection in others. In such cases there is grave danger of cathodic corrosion in the sections receiving an excessive amount of current. In each case the effectiveness of the cathodic protection installation is checked by means of the duct survey.

Tape Protected Cable—Tape protected cable is used in certain areas where corrosion is caused by local soil and duct conditions and where drainage or other electrical methods for protection are impractical. The tape covering which has been most generally used consists of coating the cable sheath with an asphalt compound and applying two layers of canvas tape saturated with the compound. This type of covering has afforded adequate protection for

ten years or more under the most severe corrosive conditions existing on the system. However, considerable difficulty has been experienced in pulling this type of cable into or out of the cable ducts because of the increased overall diameter of the cable and the tendency of the compound to cement to the duct walls. In some cases where attempts were made to remove the cable, it was found that the fabric had disintegrated and clogged the duct so as to make cable removal impossible. In such cases the ducts have to be abandoned.

Because of these difficulties, a special rubber-faced tape has been used in some of the recent installations. The rubber tape is applied to the cable in two layers after which the tape is vulcanized and mica dust is applied. The surface has a smooth finish which is of considerable aid in pulling the cable into the duct. A quantity of the rubber covered cable was installed on an experimental basis in 1940 to determine its durability and characteristics as a protective coating. To date, there have been no failures in this type of coating.

Cable Grease Protection—A special cable grease is being used extensively on the cable system for protection in areas subject to the environmental types of corrosion. This type of protection has been used on the power cables in New York City for the past four years. Another company has had ten to fifteen years of experience with grease-coated cable. The results reported to date have been generally satisfactory.

The grease compound used is a heavy, tacky petroleum grease very similar to axle grease. A little light oil is added by the manufacturer to make the grease workable. The grease is applied to the cable sheath by hand as it is pulled into the duct, care being taken to have the grease rubbed on all parts of the cable. The quantity applied amounts to approximately 25 pounds per 100 feet on cable having an outside diameter of 3 inches and proportionately less for smaller cable. In the use of grease for cable sheath protection, it is important that the cable be installed in clean ducts. Any sand or mud in the duct will mix with the grease and leave a flaky coating without protective value.

Cleaning and Flushing Cable Ducts—In cases where the cable sheaths are subject to chemical corrosion or in ducts in which alkaline or acid conditions exist, very beneficial results have been obtained by flushing the duct with hydrant water before installing the cable. Several corrosive conditions have been cleared up by this process. In one case, where ducts enter a substation through a massive concrete envelope, the ducts were flushed every three months for approximately one year before the recurrence of an alkaline condition was finally stopped.

The Use of Zinc for Cathodic Protection—Zinc electrodes are used in several system transformer manholes to provide cathodic protection to the transformer banks. The electrodes, consisting of zinc bars 36 inches long and ½ x 4 inches cross-section, are placed on the walls of the manholes, bonded together and connected to the transformer tanks.

The zinc installations in question have not been in service for sufficient time to determine their effec-

tiveness. The potential between the electrodes and the steel tank amounts to approximately 0.45 volt. The zinc is anodic and there is a definite flow of current from the electrodes to the tanks, which are painted so that this current reaches the metal through the pores and small defects in the paint coating. The current amounts to approximately 0.4 ampere for each transformer tank.

Insulating Joints—Sheath insulating joints are used to a limited extent on the power system cables where breaking the electrical continuity of the sheath will aid in reducing a stray current electrolysis condition. They are most frequently used in connection with cable sheath drainage for the purpose of limiting the drainage current or to control its distribution to parts of the cable system requiring protection. When used on power system cables it is necessary to shunt the joints with suitable resistors or to bypass them with long insulated cables to provide a path for fault current in the event of a cable failure. In some instances, a special discharge gap is connected across the joint for protection against high voltage. This gap, which was specially designed for the purpose, will break down at approximately 250 volts and carry fault current up to 20,000 amperes for a time sufficient to clear the feeder.

Summary and Conclusion

The mitigation of electrolysis on underground cables is obtained through the supervision of all the factors concerned and the maintenance of the measures installed for the protection of the system. The supervision and maintenance require periodic surveys for the purpose of checking the existing conditions and to detect any new conditions that may arise. The value of the survey depends upon the test methods used and the proper interpretation of the test data. The test methods should yield data that can be correlated with the actual corrosion experienced on the system.

The duct survey has been used over a period of several years to explore the conditions existing in the duct sections between the system manholes. The duct survey data have been correlated with actual corrosion through the analysis of the data obtained in connection with a considerable number of corrosion failures. The results provide a basis for estimating the severity of corrosive conditions.

The greater portion of the corrosion experienced on the power system cables in Greater New York is caused by the environmental types of corrosion cell. The duct resistance, i.e., the resistance from cable sheath to earth, is an important controlling factor which is frequently overlooked in electrolysis testing.

Protection against environmental types of corrosion is obtained through the use of protective coatings or through the application of cathodic protection. A large percentage of the corrosion failures occur in a few, more or less well defined areas comprising a small part of the total system. The reduction of corrosion can be accomplished most effectively by concentrating on the application of protective measures in these areas.

Future development and research in electrolysis mitigation on underground systems should include fur-

ther studies of the environmental types of corrosion and the further development of existing and new types of protective coatings. A further study should also be given to the application of cathodic protection to cable systems operating in congested areas.

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Marine Corrosion Testing Station at Kure Beach, North Carolina*

THE sea-water corrosion testing station at Kure Beach was established in 1935 for the initial purpose of comparing the corrosion resistance of low alloy steels with carbon steel. Soon other materials were added to the program so that eventually comparative tests were being made on all kinds of ferrous and nonferrous metals and alloys. The testing facilities have been used also for observing the behavior of several kinds of protective coatings both metallic and organic, including antifouling formulations.

In 1940 facilities for exposing specimens to atmospheric attack were added. The atmospheric test is a one acre plot, with room for 40 racks, each of which will support from 700 to 900 specimens. At the present time, the number of specimens exposed in the atmospheric tests is about 15,000. This is believed to be the largest number of specimens on test at a single station anywhere in the world. The expense of preparing these specimens for test and caring for them makes the investment in specimens in this test lot amount to about $150,000.

The number of specimens now exposed in sea water is about 2000. During the past 10 years the number of specimens so tested has been about 4000.

Figure 1—Sea water pond at chemical plant, used for study of samples under marine corrosive conditions.

All of this testing has been essentially a coöperative effort, involving producers and users of materials and coatings. Many of those interested in the tests have visited the test site each year when specimens are withdrawn from the water for examination. The average number of such visitors during the past five years

* This material received too late to be included in the September issue. It is a condensation of data supplied by International Nickel Company.

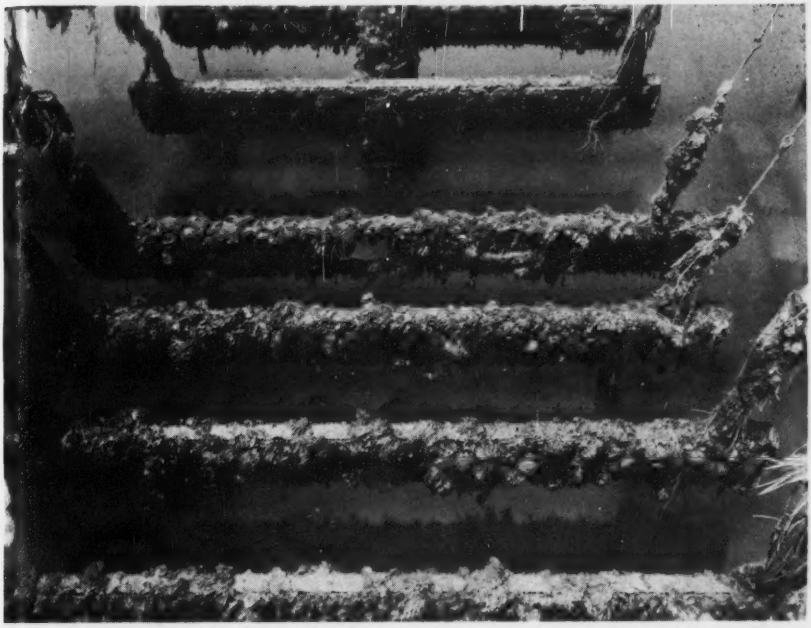
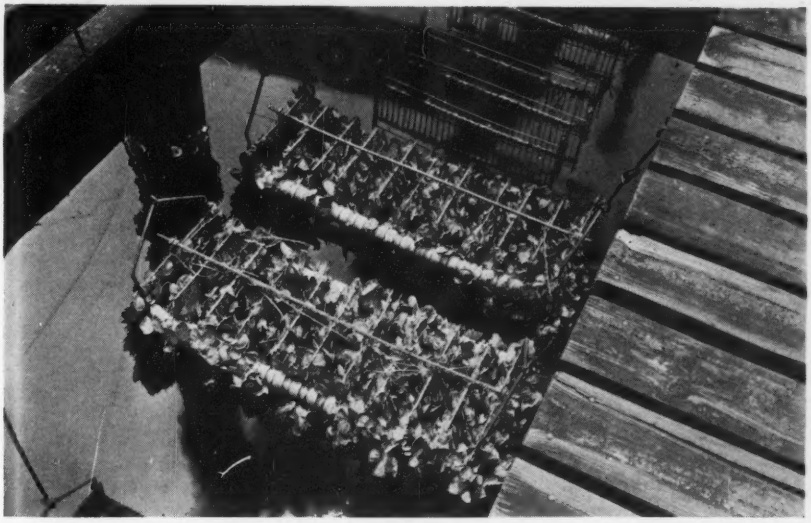


Figure 2 (above)—Racks exposed when pond is drained for examination of samples.
Figure 3 (below)—Oyster "crop" on intermittently immersed racks of specimens.



has been 50 to 60 per year, representing about as many companies, in addition to various government services concerned with sea-water and sea-air corrosion problems.

The success of this effort has been due in large part to the unusually fine facilities for carrying out sea-water tests which are provided in the channel through which sea water is pumped into a chemical plant which uses a large volume of sea water at Kure Beach. This test site has the advantage of a continuous flow of clean sea water, plus protection against mechanical damage from waves and floating objects.

The success of this entire program is due in a large measure to the enthusiastic coöperation of all parties.

Sea-Water Tests

The sea water is pumped into the reservoir shown in Figure 1 and flows through a channel into the plant at a rate of about two feet per second. This provides an ideal location for sea-water corrosion tests. Figures 2, 3 and 4 show the excessive marine growth characteristic of this area.

In this testing program it is possible to set up some tests which duplicate actual service. Figures 5, 6 and 7 show results of tests on welded steel pipe and Figure 8 shows tests on steel piling where

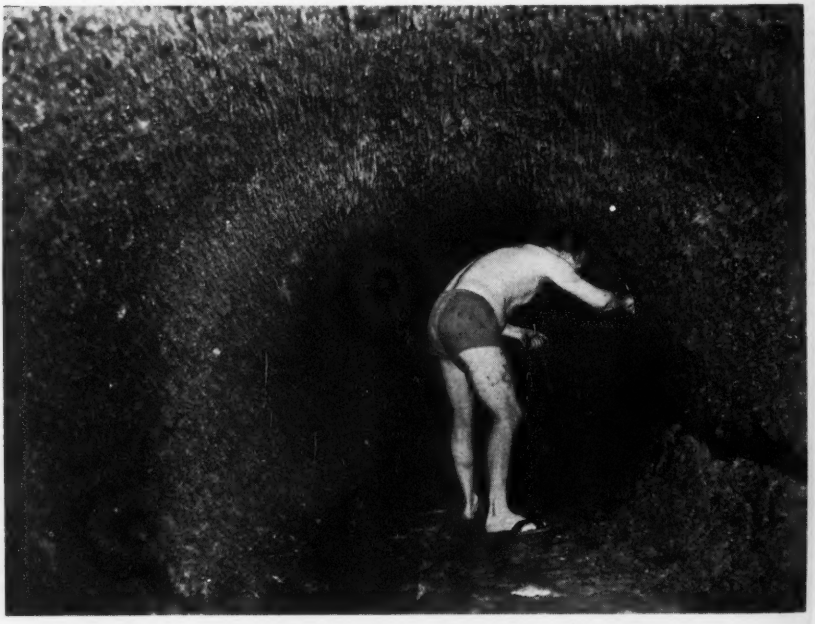


Figure 4—Interior of salt-water intake pipe to chemical plant, showing excessive marine growth in this area.

Figure 5 (above)—Typical section of steel weld after 6 years' service. Figure 6 (below)—Close-up of marine growth, showing thickness of matted material.

Figure 7 (above)—Close-up of welded area, showing condition of bead and attack adjacent thereto. Figure 8 (below)—Piling test specimens at intake basin.

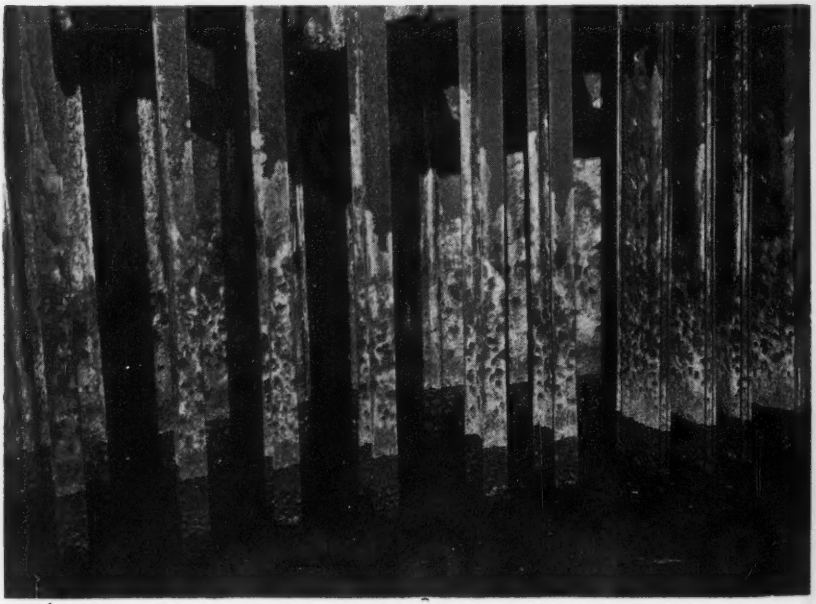
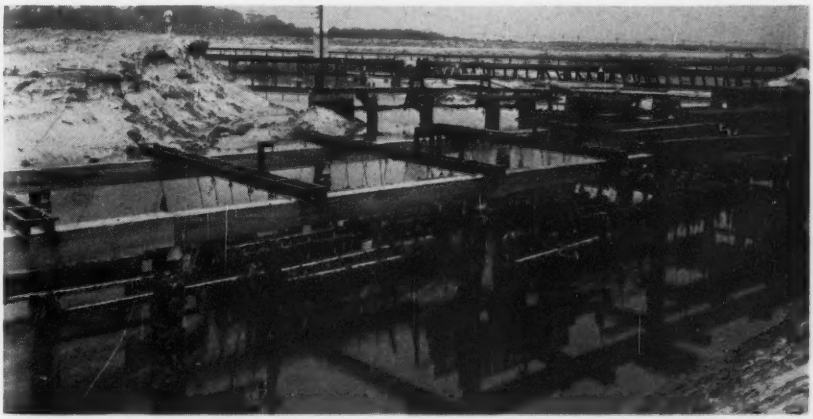


Figure 9 (above)—Racks ready for test, showing method of handling and supporting them. Figure 10 (below)—Racks exposed by draining water from intake pond.



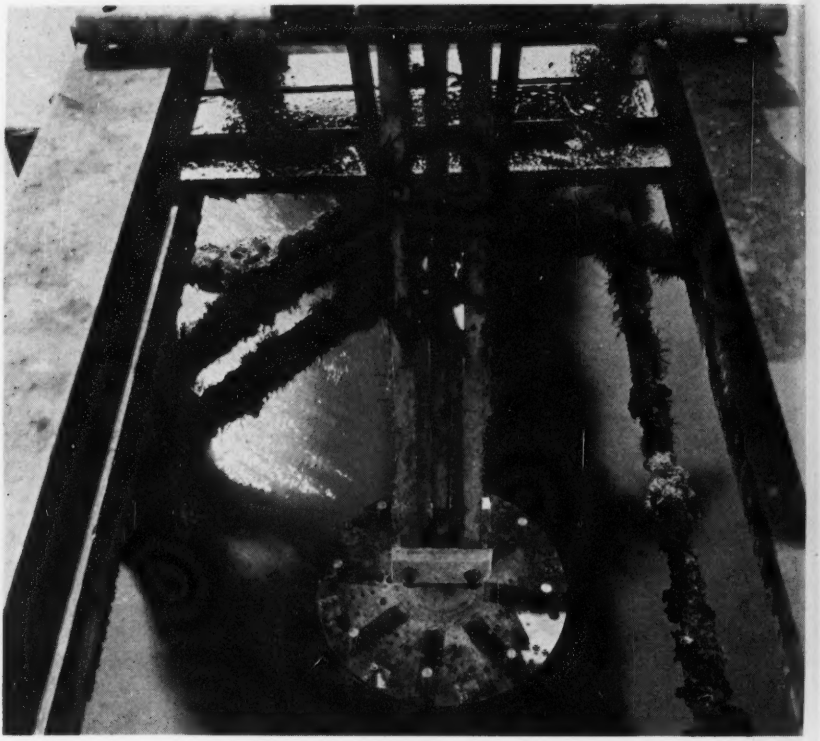


Figure 11 (above)—Erosion-testing disk exposed with pond drained. Figure 12 (below) Bars and tube brackets on erosion testing disk, showing method of attaching.

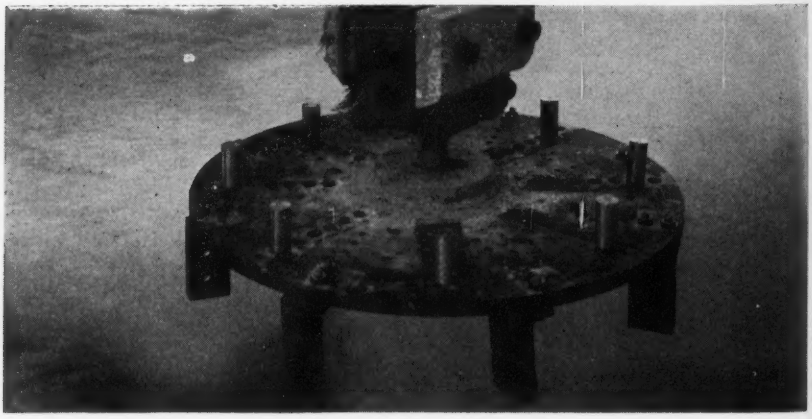


Figure 13 (above)—Variety of types of atmospheric test specimens, showing method of supporting. Figure 14 (below)—General view of atmospheric test racks and specimens.

periodical measurements show rate and type of attack.

Corrosion resistances of various alloys as well as coatings are studied under similar conditions by mounting samples on standard racks. In sea-water tests these racks are usually submerged continuously at a depth of three to four feet in the channel where sea water is flowing at rate of about two feet per second. Figures 9 and 10 show the racks and methods of handling them.

In view of the great economic importance of corrosion and erosion resistance of the alloys used in condenser tubes, pump impellers, propellers and underwater parts of fast moving ships, a series of erosion tests has also been set up. These tests have been proven to simulate actual service to a remarkable degree. The device used is shown in Figures 11 and 12.

Specimens are fastened to the disc and whirled through the stream of sea water at velocities up to 30 feet per second. All specimens are insulated from the disc and from each other. Sections of condenser tubing are placed in the braces and as the disc whirls the water rushes through the tubes under conditions of considerable turbulence. This apparatus gives every indication of providing a reliable and practical guide to the actual service which can be expected of materials in sea water at high velocity.

Atmospheric Tests

Provisions for atmospheric tests have been provided at a station approximately 250 yards from the ocean shore. Details of the test forms and the method of supporting the specimens on porcelain insulators are shown in Figure 13.

The racks face south and the frames are set at a slope of 30° from the horizontal. Figure 14 shows the general arrangement.

Editorial note: The front cover illustration is taken from one of the views of the recent examination of test specimens at Kure Beach, N. C. The racks shown are those of tension test specimens, exposed when the pond was drained. The heavy oyster and other marine growth is readily apparent.

The Behavior of Zinc-Iron Couples in Carbonate Soil

By T. H. Gilbert and Guy Corfield
Southern California Gas Company

THE behavior of zinc in electrolytic contact with steel in various types of soils has become important from the standpoint of the cathodic protection of pipe lines. In order to determine the conditions under which this type of protection may be effective, zinc-iron couples in various area ratios were recently buried at several test sites by the U. S. Bureau of Standards.

One of these test sites is a "high carbonate" soil near Los Angeles. Tests of the soil at this site gave the results in the column opposite.

Total soluble matter*	0.138%
Chlorides, Cl	0.003
Carbonates, CO_3	0.015
Bicarbonates, HCO_3	0.102
Sulphates, SO_4	0.010
pH	9.18
Resistivity, ohm/cm., Shepard Rod	2,550
Corrosivity index (nipple and can, 2 volts)	0.5

* Per cent by weight on air-dry basis.

Installation was made in September, 1941, and the couples were removed in March, 1943. Until the current tire shortage made it desirable to extend the periods between tests, measurement of electrode potentials and galvanic currents was made approximately once each month.

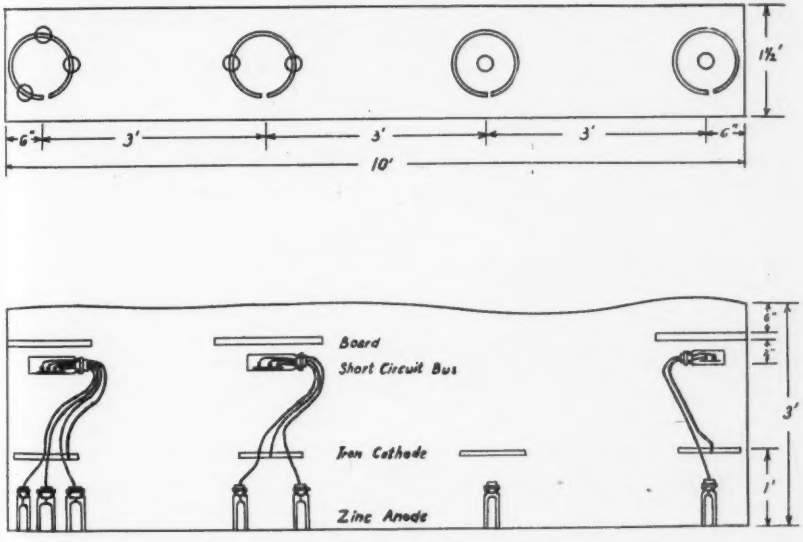


Figure 1—Arrangement of zinc-iron couples.

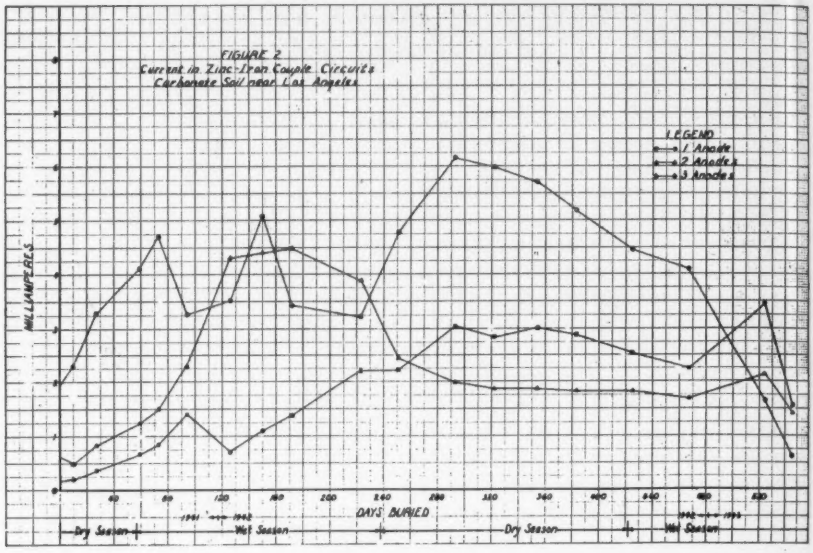


Figure 2—Current in Zinc-iron circuits. Carbonate soil near Los Angeles, California.

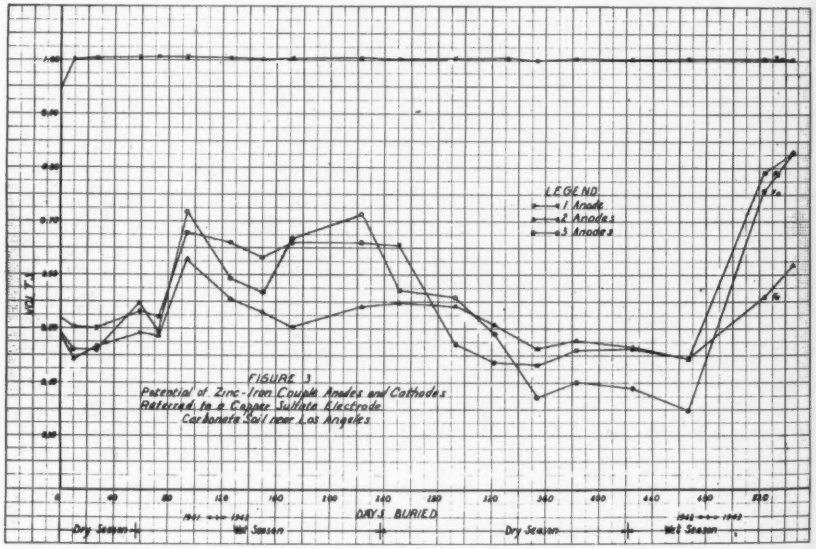


Figure 3—Potential of zinc-iron couple anodes and cathodes referred to a copper sulfate electrode. Carbonate soil near Los Angeles, California.

Each couple consisted of an iron ring connected to one or more zinc cylinders and arranged as shown in Figure 1. The entire surfaces of the iron rings were in contact with the soil. The zinc cylinders were surrounded by bottomless glass jars so that only their bases made soil contact. When installed, the area of each iron ring was 48 square inches and the area of the bottom of each zinc cylinder was 2.4 square inches.

Figure 2 shows the current flow in the couple circuit from the time of installation to the last inspection. There seems to be no very definite trend of the data over long periods. However, for approximately the first six months, the group of three anodes furnished three times the current furnished by the single anode, indicating that the cathodes were not polarized. It is also noticed that after approximately 3½ months, two anodes furnished as much current as three anodes for an interval of three months. At this time the current gradually decreased until it reached and maintained a value lower than the current furnished by the single anode. Shortly after the current furnished by two anodes began to decrease, the current furnished by three anodes also began to decrease, and on February 11, 1943, this current was the lowest of the three couples, with the single anode furnishing the most current.

In order to obtain the correct current values when taking current readings, a "zero-volt-loss" circuit was constructed and used with a multimeter in all tests. This was necessary because any meter resistance in the circuit reduces the output of the couples so that the correct

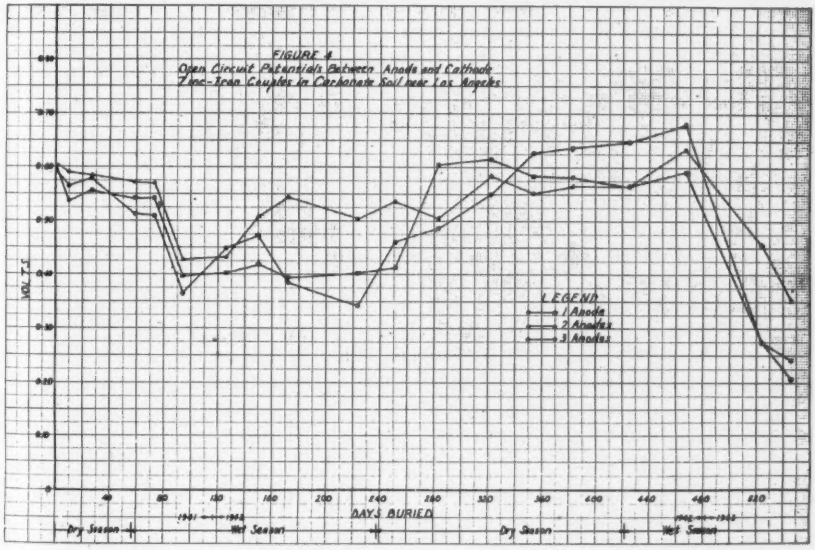


Figure 4—Open circuit potentials between anode and cathode. Zinc-iron couples in carbonate soil near Los Angeles, California.

value is not read on the scale. The "zero-volt-loss" circuit, which is shown in Figure 5, is a modification of the circuit used by Mr. I. A. Denison and Mr. R. B. Darnielle in conducting preliminary laboratory tests for the Bureau of Standards. A range selector, with four positions (see Figure 5), is provided in order to make it possible to balance the circuit quickly when using any scale on the multimeter from 1 milliampere to 1000 milliamperes. R_1 and R_2 provide a means of obtaining a coarse and a fine resistance adjustment. When using this circuit, the current is affected only by the resistance of the leads between the source and the galvanometer, and in most cases the lead resistance is so low as to be negligible. The resistance of the leads used in these tests was 0.36 ohm.

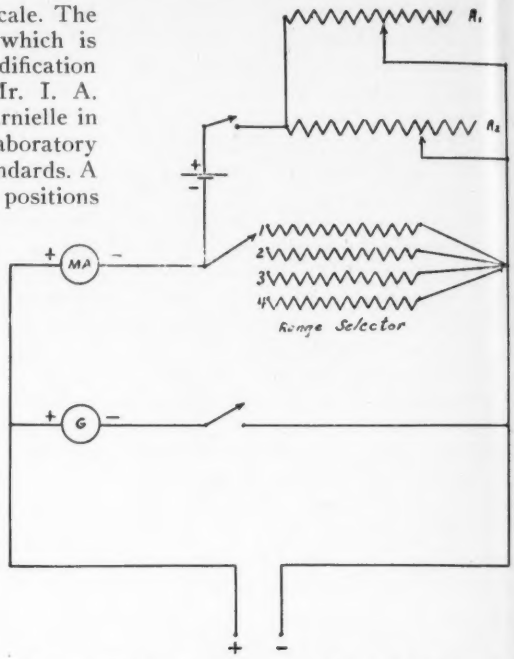


Figure 5—Wiring diagram "zero-volt-loss" milliammeter circuit.

Figure 3 shows the potentials of the iron rings and zinc cylinders with respect to a copper sulfate electrode after the circuits had been disconnected and left open for approximately one-half hour. The potential readings were taken with a Leeds and Northrup potentiometer. After the first inspection, no appreciable change in the potential of the anode with time was observed. The potentials of the iron rings range from 0.35 volt to 0.79 volt. These variations are of interest because they indicate the unreliability of iron as reference electrodes.

Figure 4 shows the difference of potential between the zinc anodes and the iron cathodes after the circuits had been disconnected and left open for approximately one-half hour. These readings were also taken with the Leeds and Northrup potentiometer. A rather wide variation of potentials is noted, being approximately 0.4 volt. There seems to be a rough correlation between these potential differences and the wet and dry seasons in this locality. It is noticed that, in general, the open circuit voltages are highest during the period from May to November, which is considered the dry season, and, with the exception of the two-anode installation, these voltages are much lower during the period from December through

TABLE I

SPECIMEN	Initial Weight Grams	Final Weight Grams	LOSS OF WEIGHT		Max. Pit Depth, In.	CURRENT DENSITY IN MILLIAMPERES PER SQ. FT.		REMARKS
			Grams	Per Cent		Initial	Final	Maximum	
Cathode No. 21	803.695	757.800	45.895	5.710	0.070	.....	.....	.....	No deposit on anode.
Anode No. 36	1023.515	1023.140	0.375	0.037	.....	.....	.....	.....	
Cathode No. 22	807.418	780.120	27.298	3.380	0.078	0.480	4.65	9.750	Max. depth of coating on base of anode equals 0.135".
Anode No. 37	1021.895	998.110	33.785	3.300	.....	.....	.....	.....	
Cathode No. 23	807.198	790.110	17.088	2.150	0.035	2.025	4.26	13.500	Max. depth of coating on base of anode:
Anode No. 38	1018.632	1002.440	16.192	1.590	.....	.....	.....	.....	No. 38 = 0.069"
Anode No. 39	1022.838	999.940	22.898	2.235	.....	.....	.....	.....	No. 39 = 0.175"
Cathode No. 24	801.945	786.670	15.275	1.902	0.041	5.730	1.89	18.450	Max. depth of coating on base of anode:
Anode No. 40	1023.298	988.670	31.628	3.100	.....	.....	.....	.....	No. 43 = 0.175"
Anode No. 41	1023.582	1008.660	14.922	1.458	.....	.....	.....	.....	No. 41 = 0.100"
Anode No. 42	1019.188	992.900	26.288	2.580	.....	.....	.....	.....	No. 42 = 0.200"

Key to Zinc Anode and Iron Cathode Numbers:
Numbers 21 and 36 Unattached.
Numbers 22 and 37 Connected together electrically.
Numbers 23, 38 and 39 Connected together electrically.
Numbers 24, 40, 41, and 42 Connected together electrically.

Analysis of Zinc used in casting anodes in foundry:

Pb	0.007
Fe	0.005
Cd	0.005
Al	0.000

April, which is considered the wet season.

After the couples had been buried for 546 days, they were removed from the soil and the zinc anodes and iron cathodes were cleaned and weighed. The cathode rings were first wire brushed and then cleaned by making them cathodes in a 2% sulphuric acid solution. A white deposit, varying in thickness from 0.069 inch to 0.2 inch, was found on the base of every anode with the exception of the unattached anode. This deposit, presumably zinc carbonate, was scraped off for analysis, and the entire zinc cylinder was then wire brushed.

Table I shows the results of the investigation. Although no attempt has been made to analyze the data, it is apparent that none of the cathodes received adequate protection. It is also indicated that the coating formed on the anodes, when buried in a carbonate soil, reduces the current output to such an extent that no great advantage is gained by providing a large anode area.

Control of Pipe-Line Corrosion—A Manual

By O. C. Mudd
Chief Corrosion Engineer, Shell Pipe Line Corporation

DECAY of man's handiwork prevails the world over. It is particularly rapid in underground engineering structures where destructive forces and elements often work undetected until failure occurs. When preventive measures are omitted or cease, decay proceeds apace.

On buried steel pipe lines, decay takes the form of corrosion which is caused principally by action of soil chemicals that combine with the pipe metal in the presence of moisture. The action is electrochemical, and it sets up electrical forces that can be detected by electrical instruments without excavation of the pipe. The analysis of instrument readings shows the areas of active corrosion and the degree of severity. Similar electrical surveys along the routes of proposed new lines permit limited prediction of the degree of soil action to be expected.

Corrosion of buried pipe lines can be retarded by suitable protective measures. Protective paints and coatings were tried at first, with but mediocre success. After the electrochemical nature of the soil action was confirmed, installations aimed to neutralize or reverse the destructive pipe-to-soil currents gave gratifying results. Present trends in protection are to combinations of electrically-resistant coatings and electric counter-current installations. The justifiable cost of such protection is now the governing factor in corrosion mitigation, a term which herein means retardation rather than complete prevention.

An understanding of electrochemical reactions associated with corrosion is necessary for an intelligent approach to the problems of survey and protection.

The reader is to be reminded that advancements is continuing in the art of corrosion control and the methods or practices described in this report may be subject to revision or become obsolete through future developments or discovery.

THEORY OF CORROSION

Any material exposed to the elements will eventually change to the state which is most stable under the conditions. Most structural metals have been converted from an ore, and they tend to revert back to that state when exposed to the elements. The original conversion process consumed heat or electrical energy which will be liberated when the reversion occurs.

The ferrous materials most commonly used in underground pipe lines have been obtained principally from iron oxides, which are of essentially the same chemical form as "rust." The appearance of rust on iron structures indicates that the metal has been attacked by corrosion and these corrosion products

are the result of the reduced metal returning to a more stable form. Rusting or oxidation may continue or be arrested according to the environment of the metal. Corrosion of metallic surfaces readily occurs in the presence of water or aqueous moisture at temperatures between the freezing and boiling points.

Electrochemical Cells

As before stated, corrosion is basically an electrochemical action, i.e., it involves metals, chemicals and electric current which in nature form electrolytic or galvanic cells. All such cells have four basic components, to wit: (See Figure 1.)

a. The "electrolyte," which is composed of water and dissolved chemicals. It usually is homogeneous in a true aqueous solution, but in moist soil it may vary locally as to the concentration or kind of dissolved chemical. An electrolyte will conduct electric current.

b. The "Anode" which is a metal or substance in contact with the electrolyte capable of conducting electric current. With few exceptions the surface is oxidized or "corroded" by combining with chemicals in the electrolyte. The term "oxidation" was originally used to describe the reaction in which oxygen combined with another element but the broader use of the term now describes the action where an atom loses electrons and becomes a positively charged ion.

c. The "cathode," which is a metal contacting the electrolyte. Its surface is not reduced but receives protection against corrosion.

d. The "conductor," which externally connects the anode and cathode to complete the circuit for current flow.

The general term for either cathode or anode is "electrode."

Classification of Cells

Electrochemical cells fall into three general groups, to wit: (See

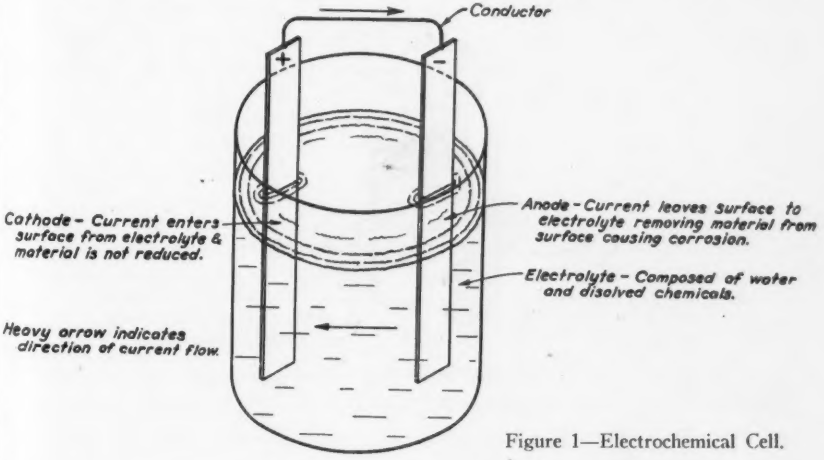


Figure 1—Electrochemical Cell.

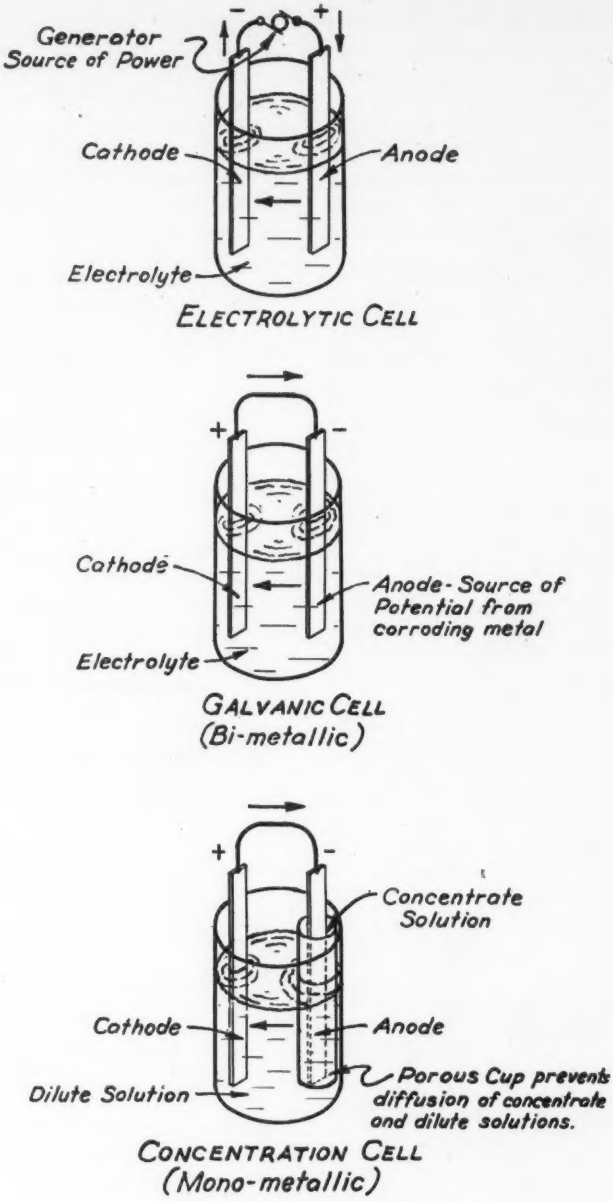


Figure 2—Types of electrochemical cells.

Figure 2.)

1. "Electrolytic" cells, which include the above-listed four components *plus an external source of electric energy* connected in the conductor between anode and cathode to cause current flow. This is the type of cell used for electrolytic refining of metals. It is the type set up for electrically protecting pipe lines against corrosion when a source of externally-generated direct-current power is available.
2. "Galvanic" cells, which have the four basic components, with dissimilar metallic electrodes in a homogeneous electrolyte. The common dry battery is typical. The metallic anode reverts to a more stable form by combining with chemicals from the electrolyte and thereby liberates the energy stored in the metal to cause electric current flow through the electrolyte from anode to cathode. Current returns through the external metallic circuit from cathode to anode. The external metallic circuit connection to the anode is negative in polarity; that to the cathode is positive. This type of cell is established when zinc or anodes of similar metals are used to protect iron pipes against corrosion without an external source of electric power.
3. "Concentration" cells are similar to galvanic cells except that they have anode and cathode of the same material in a non-homogeneous electrolyte. The differences either (1), of chemical concentration; or (2), of kind of chemicals, in the electrolyte cause current flow. In case (1) the anode is usually established in the concentrated portion of the electrolyte. In case (2) the anode will be established in the kind of chemical that combines most readily with the electrode material.

Conditions may occur also where electrochemical cells are a combination of the above types of cells. Both galvanic and electrolytic cells may be constructed to give variations in results at both anode and cathode.

This report considers only the cell conditions associated with pipe-line corrosion and its mitigation. These include "electrolytic" cells wherein current from an external source reduces the anode with simultaneous decomposition of water into oxygen and hydrogen, the latter being deposited on the cathode surface. Such conditions are prevalent in "stray" current electrolysis and in counter-current mitigation methods. These include also "galvanic" and "concentration" cells wherein the anode material combines with soil chemicals to cause current flow which also deposits hydrogen on the cathode. The latter conditions prevail in soil corrosion — whether caused by differences of metals (to form galvanic cells) or differences of chemicals (to form concentration cells).

Galvanic Cells

"Galvanic" cells have electrodes of dissimilar metals or conducting materials in a homogeneous electrolyte. The dissimilarity causes one metal to become the anode and the other a cathode, thereby forming a battery action. Two different specified metals in the same electrolyte always produce the same potential

(electrical pressure) between them. The current flow through a completed circuit will be in direct proportion to the potential between the two metals and inversely proportional to the resistance of the circuit. This will be constituted of the resistance through the increments of the metallic circuit, resistance through the electrolyte, and may often include counter potentials which develop at the electrode surfaces to produce effects equivalent to resistance.

The potential relation between metals is called the "Electromotive Series," and is listed below:

Electromotive Series using Gold as reference*

METAL	Potential to Gold
Gold (auric)	0.00 volts
Platinum	0.50 "
Lead	0.56 "
Copper (cupric)	1.02 "
Tin (stannous)	1.49 "
Nickel	1.59 "
Cadmium	1.76 "
Iron (ferrous)	1.80 "
Chromium	1.91 "
Zinc	2.12 "
Maganese	2.46 "
Aluminum	3.06 "
Magnesium	3.76 "

* Compiled from 27th Edition Handbook of Chemistry and Physics.

The value of gold is chosen arbitrarily as *zero*, and the figures listed opposite other metals are the potentials which would exist between gold and those baser metals in an electrolytic solution of a salt of the metal. In the order of the above arrangement, any metal below another will oxidize or "corrode" when connected to the one above and immersed in an electrolyte, i.e., zinc will corrode if connected to iron and placed in an electrolyte. A potential difference will exist between them (of 2.12-1.80) equaling 0.32 volts. The above table is subject to minor variations if different electrolytes are used, but it shows what generally may be expected when galvanic cells are formed.

Concentration Cells

"Concentration" cells have electrodes of the same material in a non-homogeneous electrolyte. The inequality of dissolved chemicals causes a potential difference which establishes the *anode* usually as the electrode in the more concentrated part of the solution. Differences of kind of chemicals also produce potentials with the above electrode conditions. Reliable data are not available either for the magnitude of the potentials developed between unequal concentrations of the same chemical or for the relation of anode to differences of concentration and kind.

In both galvanic and concentration cells, metallic particles (called "ions") leave the surface of the anode to combine with chemicals in the electrolyte to liberate energy, and this energy is manifest in the form of electric current which is set up through the circuits involved. The current, or the effect of its flow, can be detected by suitable electrical instruments. In all cells the amount of metal removed from a corroding anode has a fixed relation to current flow. One ampere of current flowing for one year from a section of steel pipe will remove 20.1 pounds of ferrous iron, i.e., 20.1 pounds per ampere-year for 100 percent anode efficiency.

Polarization In Cells

When current flows in a cell, deposition of hydrogen on the cathode surface builds up a resistance to the current flow. When that surface is completely covered with hydrogen

film, which is of high electrical resistance, the current flow is substantially reduced and the cell is said to be "polarized". If—after this occurs—the source of energy is disconnected, the hydrogen will disappear at a rate controlled by action or forces in the electrolyte which tend to remove or combine with this gas deposit. The time required for complete removal of this film may vary from a few hours to several days. When such reamoval is complete, the cell is said to be "depolarized". Polarization in galvanic cells, e.g., in dry batteries, can practically stop current flow because the potential developed at the anode is not sufficient to overcome the high resistance of the hydrogen film. Thus polarization of the cathode limits the rate of anode reduction.

Cell Action on Pipe Lines

Iron (or iron alloys), the material of most pipe lines, will combine with many chemicals found in nature to form oxides, hydroxides, carbonates, sulphates, sulphides and chlorides. The last four compounds will change to oxides upon prolonged exposure to air and moisture.

Pipe lines laid underground are of necessity usually placed in soils having sufficient moisture to form electrolytes which allow current flow to and from the pipe. Such moist soil conditions are favorable for the reversion of iron to its more stable compounds. The rate of this reversion depends upon: (a), the amount of moisture present; (b), the amount of dissolved chemicals that will combine with iron; and (c), inequalities of potential along the pipe line caused by varying dispersions of items (a) and (b) plus other conditions such as inequalities of potenital caused by pipe surface conditions, inequalities of potential imposed by external direct-current generating sources in the vicinity, and the area of cathodic pipe surface with its associated polarization effect.

Cathodic pipe areas generally exceed anodic areas in extent along pipe lines. This is due to the effect of polarization which occurs as the current flows from the anodic section to deposit hydrogen on the adjacent cathode surfaces. The complete polarization of any section diverts current flow to more distance adjoining surfaces. The polarized cathode surface is thus extended until equilibrium is reached between the forces causing depolarization, resistance to current flow, and potential developed at the anode.

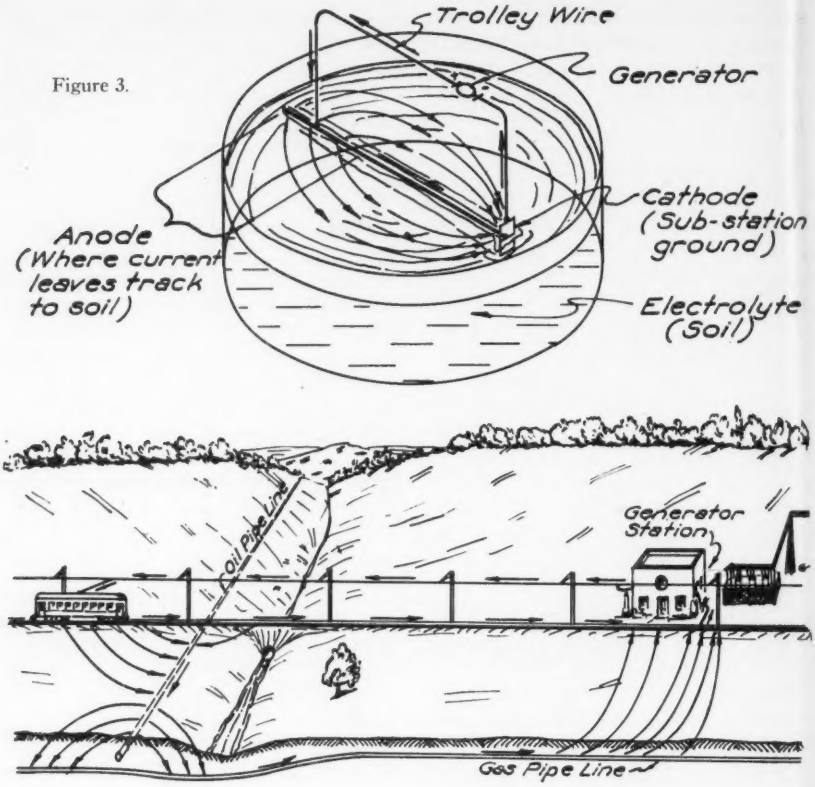
Cathodic areas maintained under partial or complete polarization account for the well-preserved condition of pipe surface usually found around a large pit-hole or adjacent to a severely corroded section, and account also for the relatively large amount of good pipe generally found in lines that have suffered numerous leaks.

TYPES OF CORROSION

Corrosion on buried pipe is of three general types, to wit:

1. Electrolytic corrosion, or "electrolysis," caused by external sources of direct current generation.
2. Galvanic corrosion, caused by combination of the pipe metal with dissolved chemicals in the soil, and
3. Biochemical corrosion results from microbiological organisms.

Figure 3.



The predominant types encountered in soil and water corrosion are sulphate-reducing bacteria.

Electrolytic Corrosion (or "electrolysis")

Electrolysis by externally-generated direct currents, termed "stray currents," is analogous to action in an electrolytic cell. A typical illustration of the analogy is shown in Figure 3. Here an insulated current-path is provided from the generator to the point of use by a trolley-wire which does not contact the soil. The principal return path to the point of current origin is the metallic track which is given good electrical continuity by welding or riveting suitable metallic conductors across the rail joints; however, secondary paths also exist. The wooden cross ties, which are the only insulation between rails and soil, absorb appreciable amount of moisture that make them somewhat conductive. The soil also is conductive to a degree and thus carries part of the return current. The current flow through the parallel paths of rail and soil

will be in an inverse ratio to the resistance of the respective paths.

If a pipe line lies near an electric railway track served by a generating station, and particularly if the two are parallel, the pipe provides another path of low resistance for part of the return current to travel. The areas of pipe where the current enters from the soil will be protected against corrosion by polarization, but those areas where the current leaves the pipe to re-enter the soil will suffer a reduction of pipe metal known as electrolysis. If a metallic "bond" of adequate current-carrying capacity is installed between the pipe and the negative side of the generator, it will reduce or even stop this corrosion.

Stray currents may be encountered in any area where direct-current generating units are operated and one or both terminals of such

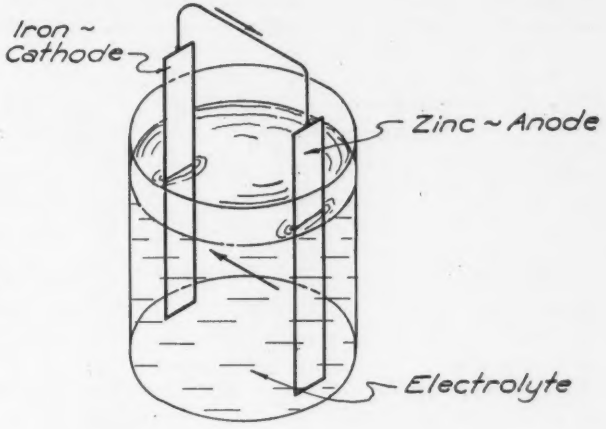
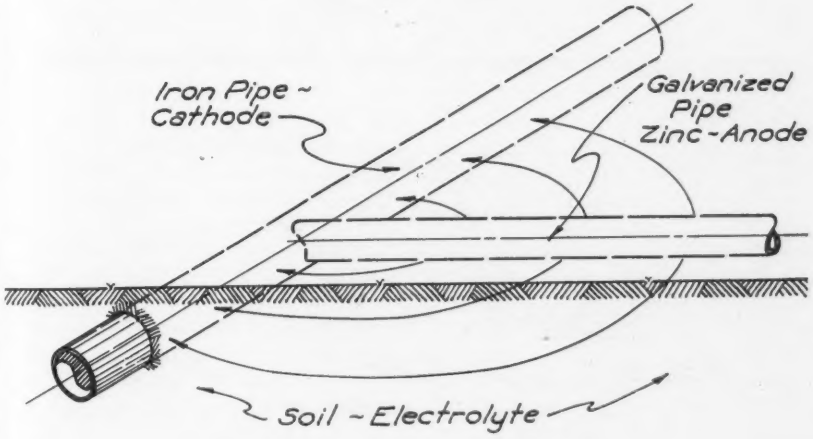


Figure 4—Iron-Zinc Galvanic Cell.



equipment are accidentally or purposely grounded. Stray current may originate even from pipe line cathodic protection units, and therefore steps must be taken to prevent the damage of any adjacent structures foreign to those protected. Grounded alternating-current circuits, because of the recurring high-frequency reversal of current flow, cause little or no damage by electrolysis.

Galvanic Corrosion

Galvanic corrosion (associated with both "galvanic" and "concentration" cells) is the greatest enemy of pipe lines. Galvanic cells, created by different metals in a homogeneous electrolyte, account for only a small portion of the total metal loss on underground pipe lines across country because such cells are usually found only at stations, in gathering and distribution systems where a composite of metals is installed. Here the pipes, fittings and equipment may be variously mild steel, galvanized iron, cast-iron, cast-steel, alloy-steel, brass, and copper. Such combinations set up a multiplicity

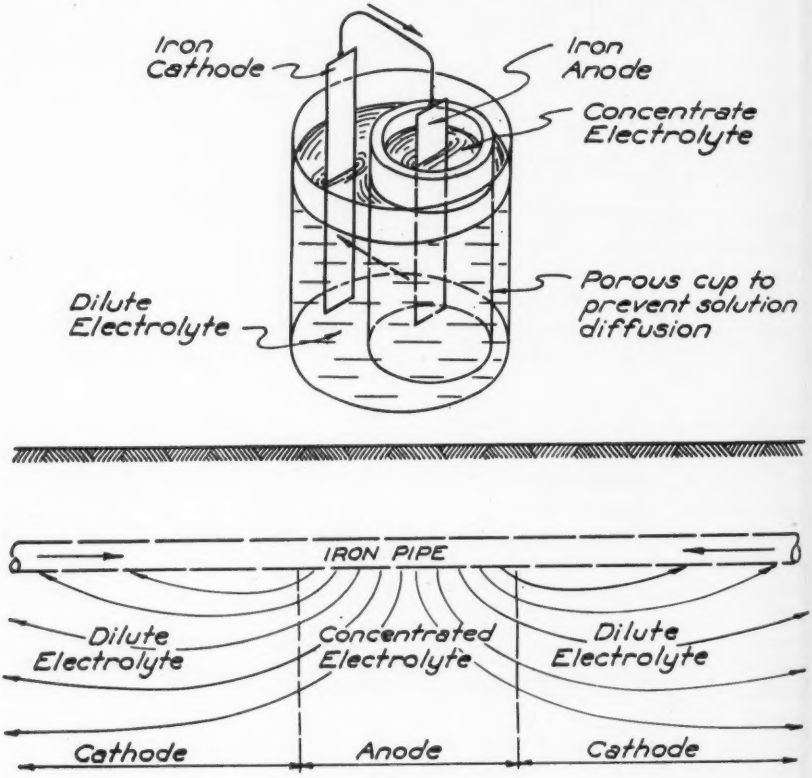


Figure 5—Concentration Cell.

of galvanic cells. Cast-iron, high-chrome steel and copper usually become cathodes, with mild steel pipe as anodes. Galvanized pipe will be anodic to mild steel until the zinc coating is consumed. (See Figure 4.) Galvanic corrosion occurs in some metals or alloys without apparent change of the metal surface, nevertheless, part of the metal or an ingredient of the alloy—when removed by electrolytic action—leaves a structure with its original shape but reduced in strength. In brass this phenomenon is known as "dezincification," in cast-iron it is called "graphitization."

Concentration cells account for most galvanic corrosion along pipe lines. These may be set up by variations in quantity of oxygen permeating through soil to the pipe, or by different concentrations of the same chemical, difference of kind of chemicals, et cetera. (See Figure 5.) Near industrial plants and municipalities, the natural conditions of chemical distribution may be augmented by spent chemical and refuse disposal. In rural districts it may be affected by the spreading of fertilizers over the soil.

Biochemical Corrosion

Biochemical corrosion results from chemicals produced by bacteria in the soil. Sulphate-reducing bacteria are the only types known at present which cause extensive corrosion in soil and water. These bacteria apparently exist in most soil and water but do not cause corrosion until the environment is favorable to their further development. Sulphates are one of the essentials for favorable environment and those in the soil are predominately under anaerobic condition (no oxygen), however species have been found in water which thrive under aerobic or anaerobic conditions. The exact nature of the chemical reactions is not known, however the bacteria in their life process cause liberation of hydrogensulphide which combines readily with iron. The resultant corrosion is "galvanic" in character but is not accompanied by electrical indications comparable to those from other types of galvanic corrosion.

Methods of locating this type of corrosion with electrical instruments from the soil surface need development although the mitigation of such corrosion presents no special problem.

METHODS OF CORROSION INVESTIGATION

Original Surveys Made on a Pipe-Line System

Methods of investigating corrosion on an oil pipe line system have continued to develop since the initial survey over the trunk lines during 1933 and 1934. This survey extended over 2200 miles of line. More than 1800 inspection sites were excavated to gather information regarding soil conditions, coating types and conditions, maximum depth of corroded pit-holes, soil resistivities and line-current flows. Correlated data from this survey revealed that approximately 80 per cent of the previous leaks on the system were in sections indicated by electrical measurements as suffering corrosion. In later surveys, where spacing of inspection sites was reduced, this percentage was raised to near 100.

This extensive survey demonstrated the practicability and advan-

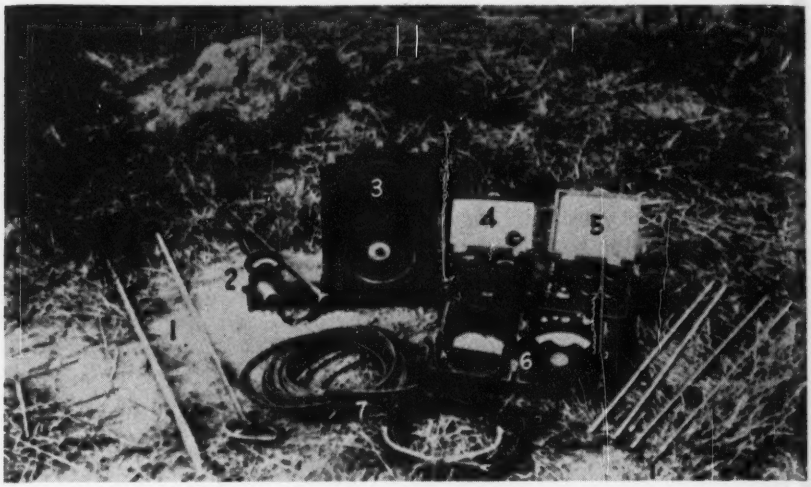


Figure 6—Some of the instruments and equipment used in corrosion mitigation work. 1, Pipe locating bars. 2, Shepard cane earth resistivity meter. 3, Millivolt recorder. 4, Multi-range potentiometer. 5, Resistance bridge. 6, Electrolysis volt-ammeter. 7, Test leads. 8, Pipe contact bars (with extra points). 9, Pipe contact bar extension rods.

tages of electrical measurements over other methods of corrosion investigation then normally practiced. Through study of test data taken in the field, a better understanding of the electrochemical action associated with corrosion was acquired, and the resolution of corrosion areas into the component parts of electroyltic cells (illustrated in Figures 1 to 5) resulted in the evolution of better methods and practice.

Electrical Instruments Required

Fundamental measurements for study of pipe-line corrosion cells include those of current flow, potential difference or "gradient," and soil resistance. Electrical instruments are necessary for this work. Such instruments should be accurate and dependable, constructed to withstand hard field usage, and of the least possible weight.

Instruments are required for the following basic measurements:

1. Potential *indications* between a fraction of a millivolt and 100 volts.
2. Potential *recordings* over the same range.
3. Current *indications* between a fraction of an ampere and 100 amperes or above.
4. Current *recordings* over the same range.
5. Soil resistivity measurements from a few ohms per cubic centimeter up to 10,000 or over.

The instruments found most dependable are listed below and shown in Figure 6. They are:

1. Electrolysis Volt-Ammeter (D'Arsonval Type) Calibrated

NOTE: Measurements of currents, whether indicated or recorded, can be made with millivoltmeters and suitable shunts or calibration of pipes through which current flows.

for full scale reading of:

Volts	Amperes
0.005—0— 0.01.....	0.5—0— 1.0
0.05 —0— 0.1.....	5.0—0— 10.0
0.5 —0— 1.0.....	50.0—0—100.0
5.0 —0— 10.0.....	Sensitivity 300 ohms per volt
50.0 —0—100.0.....	

2. Multirange Potentiometer (Slide-Wire Type including Standard Cell.) Calibrated for full scale readings of:

0— 5 Millivolts...	20-ohm Galvanometer
0— 100 Millivolts...	
100—1000 Millivolts...	

With booster circuit to add three volts by one-volt steps.

3. Millivolt Recorder (Vibrating Pen Type) with variable chart drive speeds, preferably one-hour and 24-hour drives for circular charts. Calibrated for full scale recordings of:

Millivolts	Volts
5—0— 5.....	2.5—0— 2.5
25—0— 25.....	10.0—0— 10.0
100—0—100.....	50.0—0— 50.0
500—0—500.....	100.0—0—100.0
	Sensitivity 400 ohms per volt

4. Earth Resistivity Meter (Shepard-cane type) with 30-inch rods calibrated to read full scale of 100—500 and 400—10,000 ohms per cubic centimeter.

5. Earth Resistivity "megger" (Magneto Type) with full scale 0—3 and multiplier circuits of 1, 10, 100 and 1000. This instrument is a four-electrode type which permits average soil resistivity determinations at varying depths by electrode spacing at the soil surface.

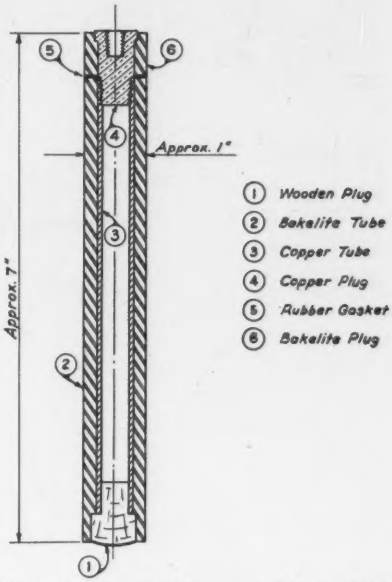


Figure 7—Saturated copper-sulphate "half cell" electrode.

6. Supplementary equipment, comprising:

2 (or more) half-cell electrodes (copper sulphate) used in making contact with soil for potential measurements. (See Figure 7.)

2 pipe locating bars. (See Figure 8.)

4 pipe contacting bars. (See Figure 9.)

2 pipe connection clamps. (See Figure 10.)

2 test leads, 115 feet long.

2 test leads, 25 feet long. (The above test leads to be No. 10 or 12 B & S gauge single-conductor, 133 strands, with portable cord insulation and suitable terminals at each end. (See Figure 12.)

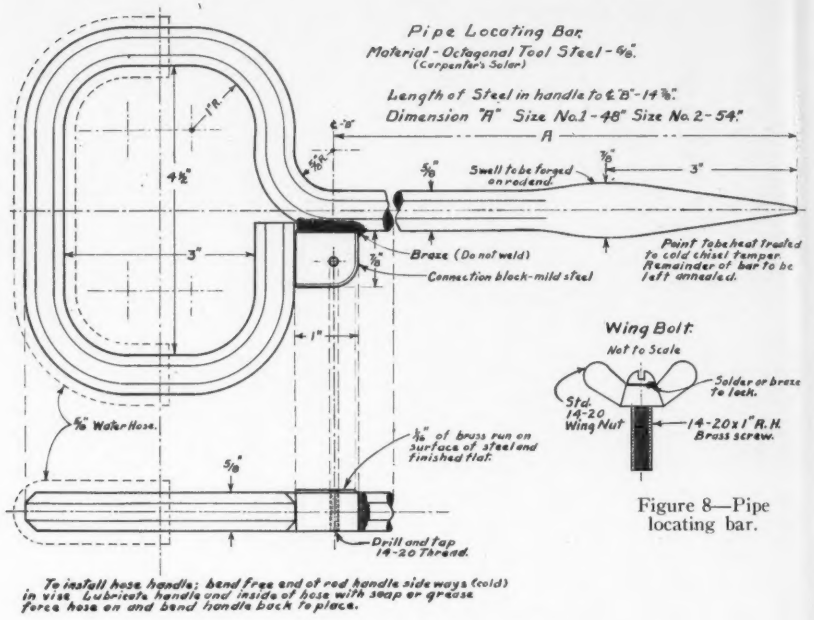
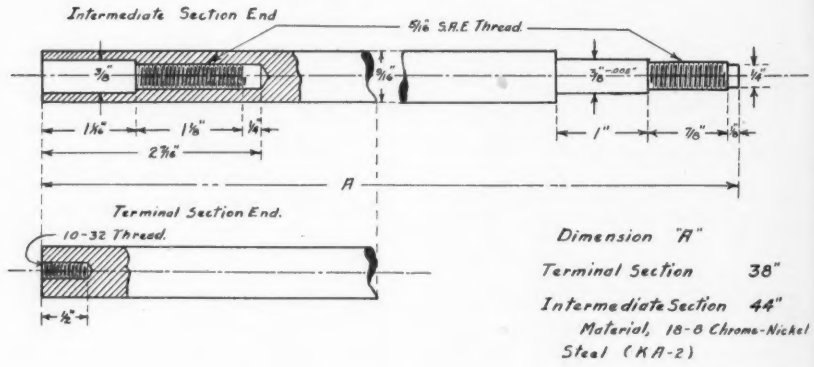


Figure 8—Pipe locating bar.



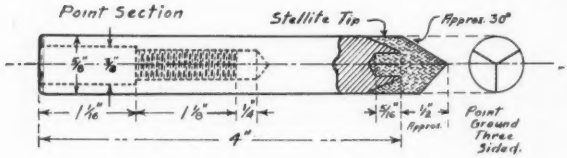


Figure 9—Contact rod and point.

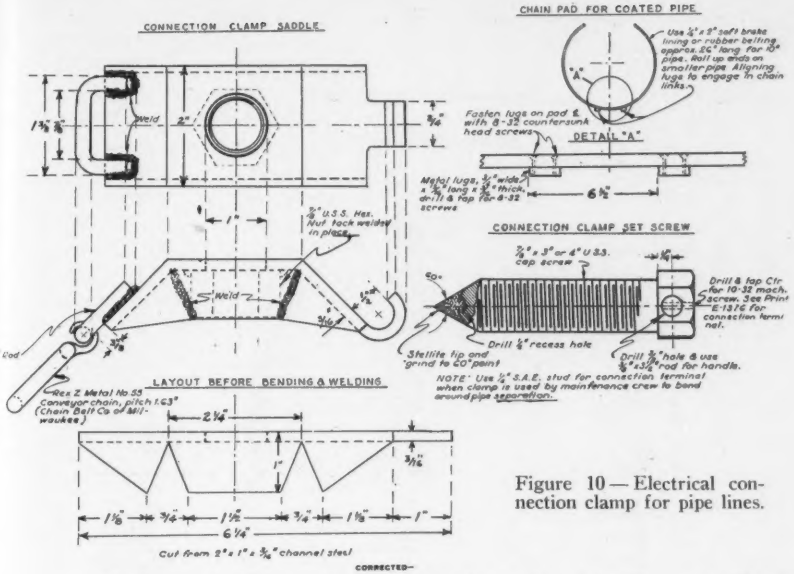


Figure 10 — Electrical connection clamp for pipe lines.

Various short test-leads with terminals as required.

1 Resistance Bridge (Wheatstone Bridge.)

This instrument is useful in checking test-leads and locating faults in metallic circuits.

The above list may be altered to suit requirements. Potentiometers and Earth Resistivity Meggers are now available that are more modern than those shown in Figure 6. These are not more accurate, but they have been made lighter without sacrifice of dependability.

Electrical Measurement

To determine the rate of metal loss from the anode in a simple cell, the current flow can be measured in the conductor between anode and cathode. However, where a pipe line serves as the conductor between

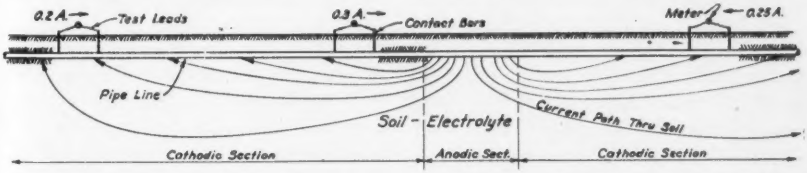


Figure 11—Illustration of line current determinations to locate anodic sections of pipe. Line current determined by measuring potential drop at consecutive locations between contact points with identical spacing for each measurement. Current magnitude calculated from known pipe resistance and measured potential drop. Polarity of connections at the meter determines direction of current flow. Current loss by convergence or reduction of amount in one direction indicates anodic section.

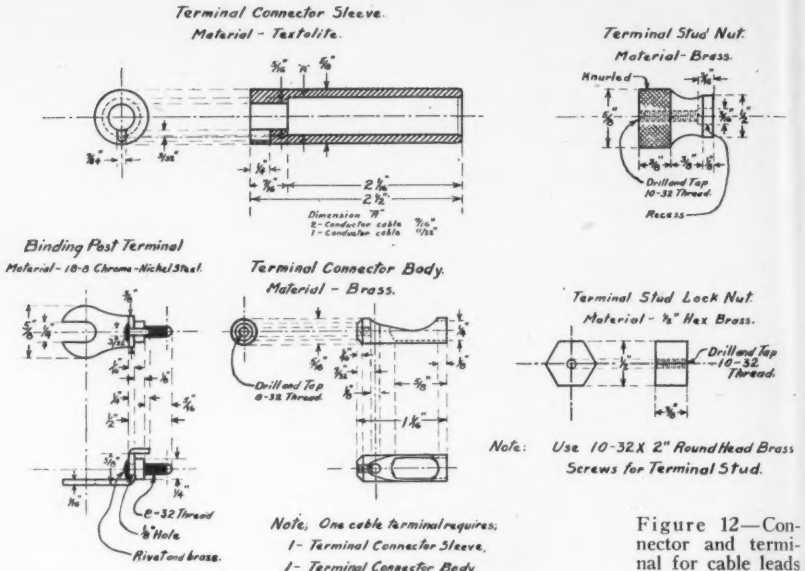


Figure 12—Connector and terminal for cable leads and clamps.

its anodic and cathodic sections, one cannot disconnect the pipe between these sections to insert an ammeter in the circuit. The most practical alternative is to measure the potential drop along selected sections of the pipe, and to use these voltage readings to calculate the current flow; however, the electrical resistance of the pipe must be known. This resistance may be obtained from tables, or it may be calculated from known weight of metal per unit length. Also, it may be determined in a detached piece of the pipe by establishing a known current and measuring the resultant potential drop.

Measurements of potential drop and direction of flow at suitable intervals along the pipe line indicate the magnitude of average current flow in the intervals, and from such consecutive measurements the sections of current gain (cathodes) and current loss (anodes) can be approximately located.

Potentials measured between pipe and soil, or potential gradients measured between adjacent contact points on the surface of the soil over the pipe, also will indicate anodic and cathodic sections. Soils always have much higher resistances than pipe metal, consequently current flows cause much greater potential drops in the soil that are easier to detect. Also, the *direction* of the current flow in the soil is indicated by such measurements; however, its *magnitude* can be only approximated after resistance of the soil in the vicinity has been determined.

Soil resistance is measured as "resistivity," i.e., the resistance between two faces of a unit (cubic centimeter)

soil cube. Knowledge of soil resistances is important because they indicate the relative amount of dissolved chemicals and serve as an index of the amount of current that may flow with a given potential. Their measurement, however, does not tell what *kinds* of chemicals are present. Wherever the latter information is desired, it must be obtained by chemical analysis.

Consideration at one time was given to the development of equipment to detect and measure pipe-line currents—without contacting the pipe—through measuring the variations in magnetic fields set up by the currents; however, this technique was abandoned because the resultant data could under many circumstances lead to erroneous deductions.

Along existing pipe lines corrosion surveys are based on the determination of line currents and/or surface potentials, usually the latter. The amount of data to be obtained during such a survey will depend upon how much time and labor is justified by circumstances. Interpretation of data is qualified by geographical locations, moisture content of the soil, chemical content of the soil and other factors that affect the indicated results and can best be interpreted by skilled corrosion engineers through comparison with past experience.

Along proposed pipe line routes, surveys to determine the probable corrosive areas are most practically made by means of soil resistivity measurements. Other methods have been used but, based on time required and value of information to be obtained, soil resistivity measurements are preferable in that the variations indicate potential concentration cells. However, valuable information may be obtained through visual inspection by a corrosion engineer who is familiar with corrosion experience in the locality.

Line-Current Method of Survey

Line-current determinations are confined to existing lines or structures, and this method of survey, which is equivalent to measuring the current flowing in the metallic circuit of a galvanic cell, requires special methods to locate sections of current gain (cathodes) and current loss (anodes). The latter are those where corrosion is active. (See Figure 11.)

The applicable technique involves four steps: (1), measure off a desired length of pipe line on the ground surface; (2), locate the pipe at each end of this measured section with "locating bars," (see Figure 8); (3), establish contact to the pipe with "contacting bars," (see Figure 9); and (4), measure the potential drop between these contact points. The voltmeter indicates the direction of flow; but the average amount of current flow in the measured section must be calculated, or can be obtained from prepared tables similar to those included as Figures 13 and 14. Successive measurements will show current loss (anodic) or current gain (cathodic) sections The customary distance between successive measurements in open country is 1200 to 1500 feet, but this may be altered to suit conditions.

In each measurement the potential drop between the contact points, usually inserted one hundred feet apart is normally only a fraction of a millivolt; thus it is essential that readings be made carefully if the

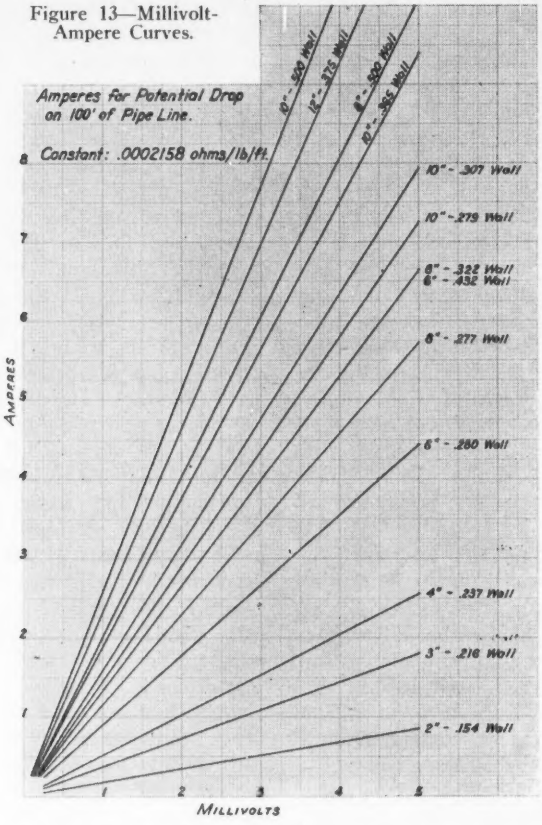


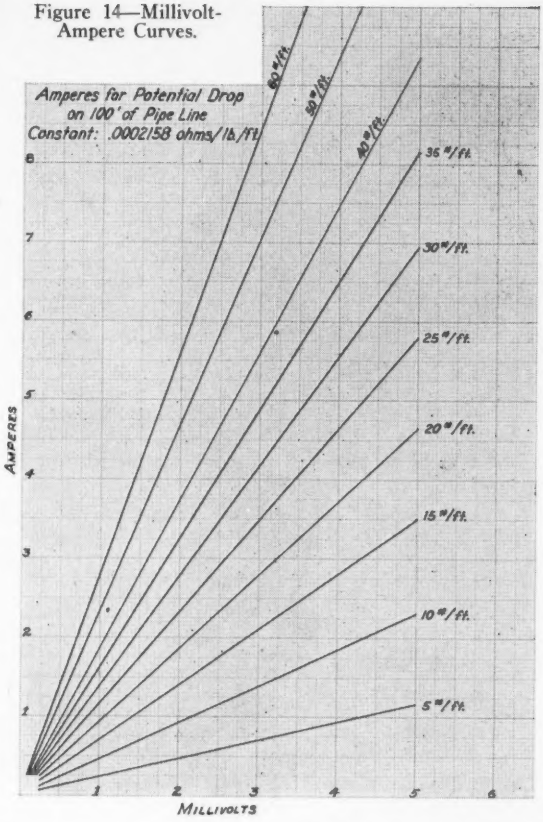
Figure 13—Millivolt-Ampere Curves.

existing anodic and cathodic sections are to be found. Isolating of anodic sections by line-current measurements is difficult because the measurable effects are relatively small and such sections are irregular in their distribution and extent. For example, three definite anodic sections have been located within 100 feet on a ten-inch line, while other individual sections have been found that are several hundred feet in length.

Where lines are conducting *fluctuating "stray" currents*, the detection of current-loss and current-gain sections requires simultaneous operation of two or more millivolt recorders to register potential drop at successive locations. The record must show clear definition of the simultaneous current variations to permit interpretation at these successive locations.

Where measurements are being obtained for current or potential *originating from soil chemical action*, a millivolt recorder should be connected through pipe connection-clamps on a section of line in the vicinty to record potential drops. Currents and poten-

Figure 14—Millivolt-Ampere Curves.



tials of soil chemical origin have little or no variation, but magnetic storms and "stray" direct currents may induce fluctuations that will nullify instantaneous observations made with an indicating meter. (See Figure 15.)

Soil Surface-Potential Method of Survey

Distribution of potential drop over the surface of a galvanic cell can be determined by potential measurements made from either electrode to various points on the electrolyte surface. This is done by contacting one side of a voltmeter to the electrolyte surface through a "half-cell" electrode and connecting the other side metallically to the selected electrode. (See Figure 16.) If two successive such measurements are made, the first with the half-cell contact near the anode and the second with it near the cathode, the difference between the indicated potentials will be the measure of the potential drop between the two contact points. The direction of indicated current flow will be from anode to cathode through the elec-

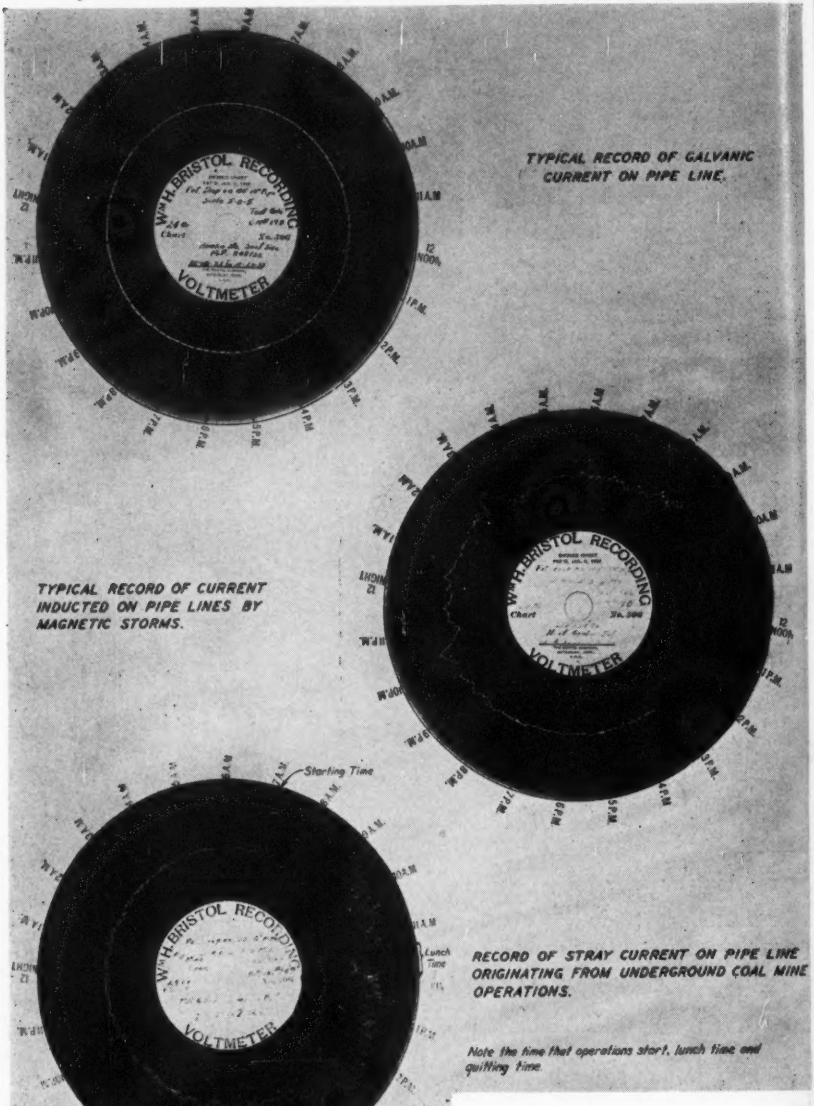

TYPICAL RECORD OF GALVANIC CURRENT ON PIPE LINE.
TYPICAL RECORD OF CURRENT INDUCTED ON PIPE LINES BY MAGNETIC STORMS.
RECORD OF STRAY CURRENT ON PIPE LINE ORIGINATING FROM UNDERGROUND COAL MINE OPERATIONS.
Note the time that operations start, lunch time and quitting time.
Starting Time
Lunch Time
Quitting Time
VOLTMETER

Figure 15.

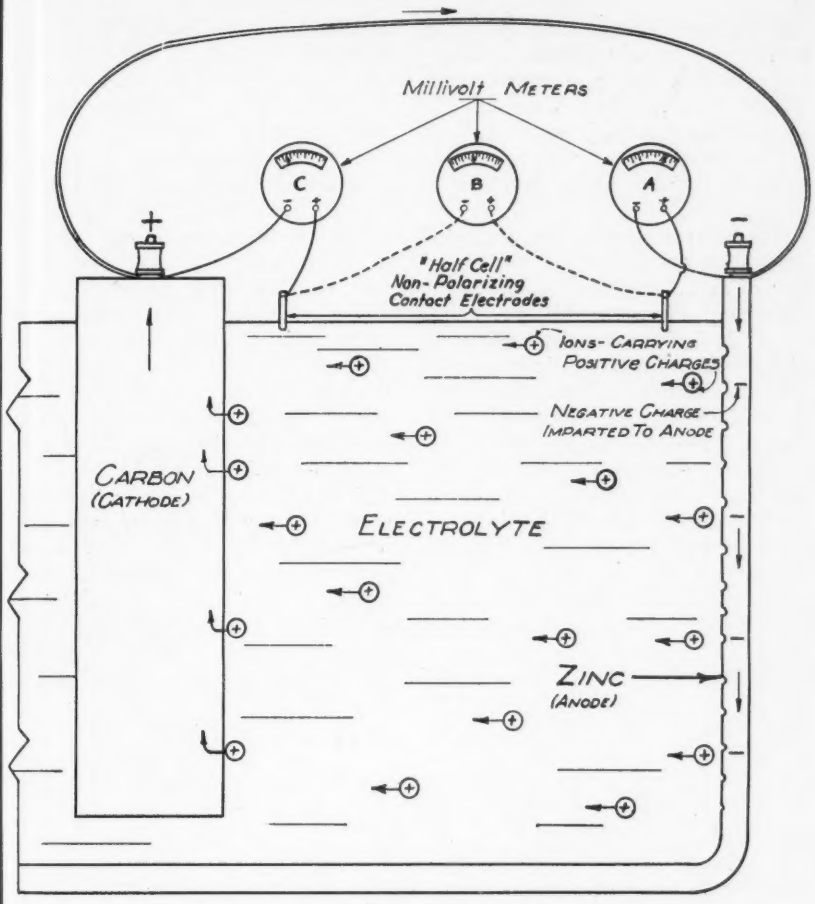


Figure 16—Illustration of Battery Action (Galvanic Cell).

trolyte, i.e., the contact point near the anode will have a positive polarity with respect to the one near the cathode.

Most of the potential drop in a galvanic cell circuit will be through the electrolyte where its resistance usually is high compared to that of the external metallic connection. Similarly, because the resistances of moist soils in which pipe lines are immersed are extremely high in comparison to that of the pipe metal. most of the potential drop occurs through the soil.

Pipe-to-soil potentials originating from electrochemical action along the line (as differentiated from those caused by "stray" currents) will show variations up to 400 millivolts between anodic and cathodic sections. The pipe is negative to the

soil in corroding anodic sections and positive to it in adjacent cathodic sections. Pipe-to-soil potential measurements at frequent intervals will identify the corroding sections. This procedure requires location and contact of the pipe for each observation.

As before stated, the potential drop between two points on the surface of an electrolyte is equal to the difference of potentials measured successively between the two points and an adjacent metallic electrode. The application of such measurements for corrosion survey of a pipe line is illustrated in Figure 17. By measuring potentials and noting the polarity between contacts on the soil surface directly above the line, one can calculate the pipe-to-soil-potential under one contact point with reference to that under the points on either side. The method is illustrated in Figure 18.

Pipe-to-soil potentials from soil chemical action, when measured with use of a copper-sulphate half-cell electrode, seldom exceed 0.40 to 0.60 volts, and such higher potentials occur only along anodic sections. Since these anodic sections of pipe are usually of relatively short length, the current flow from each section is correspondingly confined to small cross sections of soil; therefore, the potential gradients in the soil near anodes are steep. The crest of an anodic section can be found by setting one electrode away from the line and moving the other from place to place on the surface above the line until the point of highest positive reading is found.

When "cathodic" protection with rectifier or a direct-current generator is applied to a pipe line, the current source (the rectifier or generator) is external to the line and soil. Under such conditions a negative pipe-to-soil potential indicates the degree of protection obtained.

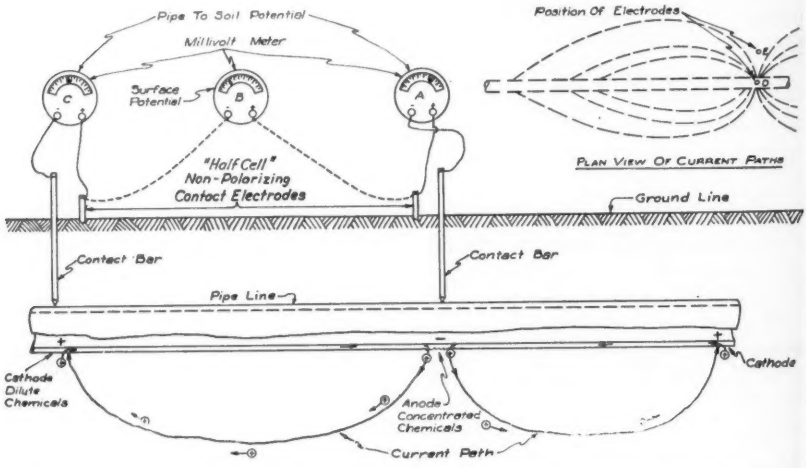
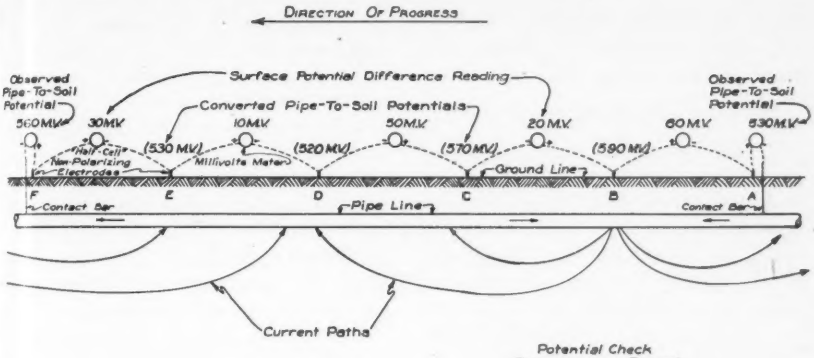


Figure 17—Sketch showing battery action on buried pipe, and method of determining pipe-to-soil potentials and surface potentials.



Potential Check	Toward A	Toward F
A-B	60 M.V.	
B-C		20 M.V.
C-D		50 M.V.
D-E	10 M.V.	
E-F	30 M.V.	
	100 M.V.	70 M.V.
	-70 M.V.	
	30 M.V.	

F A = 560 - 530 = 30 M.V.

Figure 18—Sketch illustrating method of taking surface potential reading over pipe line.

However, in making interpretations from readings with a copper-sulphate half-cell electrode, it must be remembered that potentials below 0.60 volts may be caused by galvanic action as well as by the imposed current flow, or they can be the resultant of both.

Surface-potential measurements can be made with more accuracy and in less time than line-current or pipe-to-soil potential measurements. Surface-potential values are of greater magnitude than those taken for line current, and thus likely errors are minimized. Surface measurements at consecutive 100-foot intervals can be made over several miles of line in the same time required for line current measurements to be

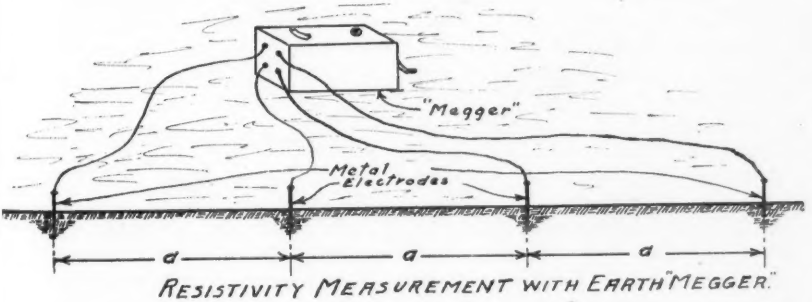


Figure 19.

taken at 1000 to 1500-foot intervals. The shorter interval readings give much more detailed information.

Soil Resistivity Measurements

Resistivity measurements of soil are based on its resistance to electric current flow. The resistivity generally is in inverse proportion to the amount of dissolved chemicals, i.e., resistivity is lowered by increase of dissolved chemicals. Corrosion of pipe lines can be expected in lower resistivity soils because they have more chemicals available to combine with the iron.

Soil resistivity measurements taken just below pipe depth are most accurate because the pipe-to-soil contact is most intimate along the bottom of the trench where excavation has not disturbed the natural formations. Frequent measurements must be made, both along existing lines and along proposed routes, to detect the radical changes of chemical concentration which often occur within a few feet in impervious clays. These variations in chemical content form "concentration cells" when interconnected by pipe lines.

The use of the Shepard-cane Earth-Resistivity Meter is practical in open trenches or in excavations where contact can be made with soil at the desired depth. The "four-electrode" method with Earth Resistivity "megger" is applicable where soil resistivities are to be obtained at various depths without excavation. This method indicates *the average of resistivity from the surface to a depth equal to the distance apart the electrodes are spaced*—usually 4, 8, 16, and 32 feet in practice. (See Figure 19.) Varying the spacing will give a better approximation of resistivity for successive substrate. These measurements can be made also with a small direct-current generator or battery and a potentiometer or vacuum-tube voltmeter. (See Figure 20.)

Radio-frequency absorption can be used to measure low-resistivity soils, i.e., soils of 1000 ohms per cubic centimeter or less; however, the method is subject to further developmen for dependable results.

Chemical Analysis of Soils

Chemical analysis of soils along pipe lines is of little value because the samples usually are taken at such intervals that intervening conditions may vary to extremes. The cost of collecting and analyzing soil samples taken every few feet is prohibitive. Also, there is a much closer correlation between corrosion and soil resistivity than between corrosion and soil analysis, and the former can be determined much more quickly and economically.

Hydrogen Ion Concentration

Extensive efforts have been made to establish a definite relation between corrosion and the "hydrogen ion concentration" ($_p$H) of soil, but none has been found. Also, the $_p$H of soil varies with seasonal changes in many locations.

Biochemical Corrosion

Soils rich in sulphates are favorable for environment under which sulphate-reducing bacteria develop until the quantity of hydrogen sulphide liberated by them causes oxidation of pipe metal to iron sulphide. A quite dependable field test for the presence of these bacteria can be made on corrosion products scraped

from the pipe. The method is to place a piece of the corrosion product in a small bottle, add a few drops of dilute hydrochloric acid, and then expose a piece of lead-acetate paper to the generated fumes. If hydrogen sulphide is liberated in the fumes, the paper turns black and gives good evidence that sulphate-reducing bacteria are present. The $_pH$ value under which sulphate-reducing bacteria develop is between 6.5 and 8.6. Laboratory technique is required for positive determinations.

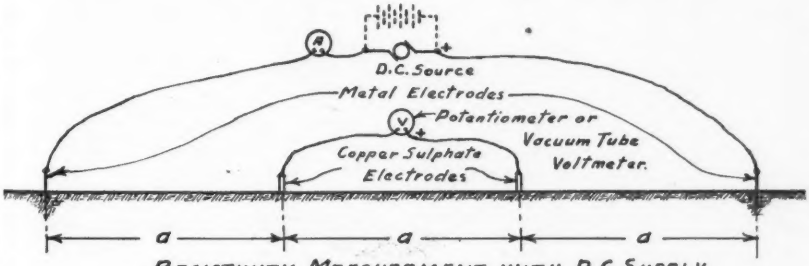
Some Survey Errors and Ways of Eliminating Them

Some of the most frequent causes of errors encountered in corrosion surveys, as well as methods of eliminating them, are discussed in the following paragraphs.

Poor contact with pipe metal causes serious errors in meter reading. Some of the factors are:

1. Dull contact bar points may cause foreign material (such as corrosion products) to become impacted between the point and pipe metal. These foreign particles in the presence of moisture set up galvanic cells that may develop potentials of greater magnitude than those to be measured. The higher such potentials are easily detected, but those of less degree may pass unnoticed and give readings that result in errors of interpretation.
2. Inequality of temperature between contact bars and pipe metal develops thermo-couple potentials. Such potentials are usually only a fraction of a millivolt, but they are sufficient to introduce serious error in line-current measurements. Thermo-couple effect disappears when the temperatures of the pipe and contact bar equalize.
3. Movements of the contact bars during measurements develop potentials from metal strain (termed "Piezo electricity") that cause fluctuations and errors in meter readings.

The above errors may be reduced



RESISTIVITY MEASUREMENT WITH D.C. SUPPLY.

WHERE $\rho = \frac{2\pi a V}{I}$

ρ and a = same as above.
V = Voltage between $CuSO_4$ Electrodes.
A = Amperes in metal electrode circuit.
When a = 1 Ft. and I = .019 Amp.
Then ρ = M.V. x 10.

Figure 20.

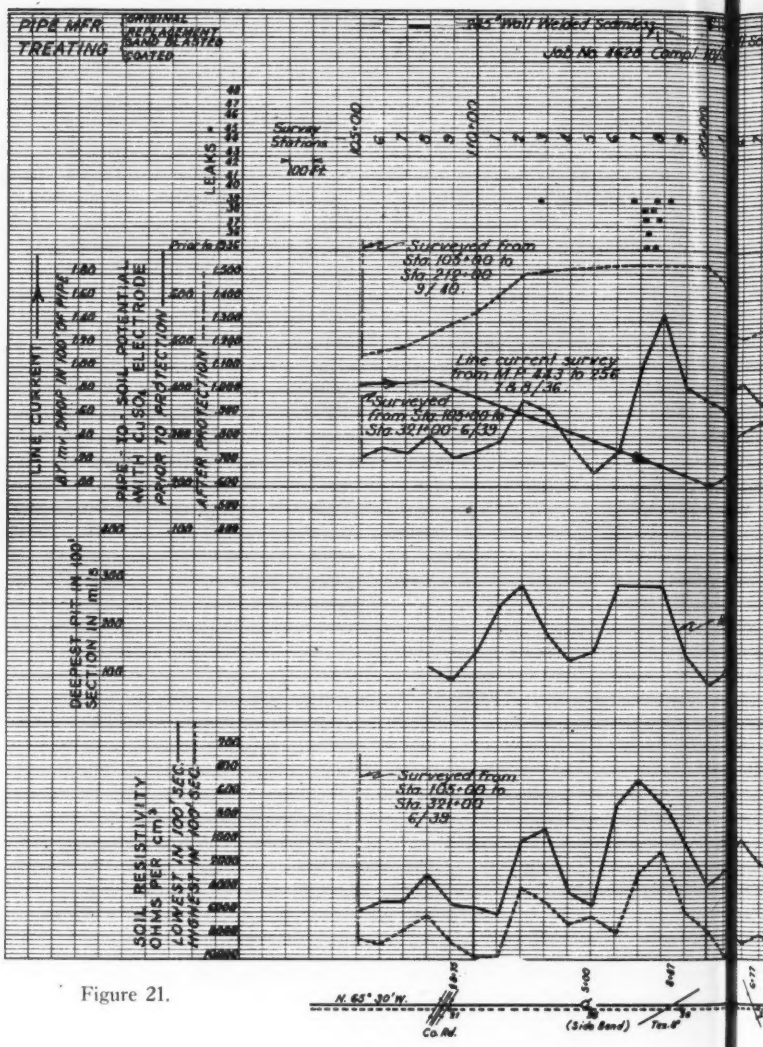
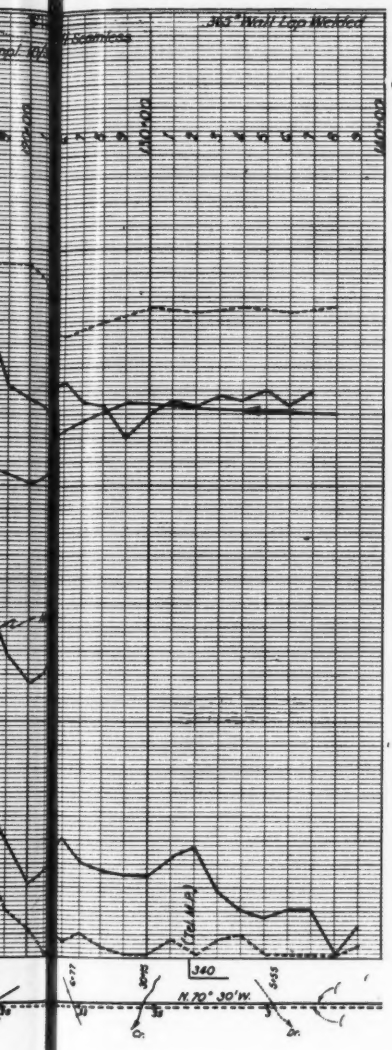


Figure 21.

or eliminated by observing the following precautions:

1. Keep contact bar points sharp. When light reflections can be detected from a flat spot or "facet" on the contact bar point, the point should be resharpened.
2. Place or keep contact bars out of direct sun rays when not in use. The points may be brought approximately to pipe temperature by making extra holes in



the soil with the *"pipe-locating" bar* and then inserting the contact bars in these holes while locating the pipe. Making unnecessary holes in soil *with the contact bars* quickly destroys their points.

3. Movement of contact bars can be stopped by training the personnel how to hold the bar and make the contact properly. Contacts are best when made vertical to the pipe surface through a hole down to the surface free of loose particles. This allows free insertion of the bar. *Contacts and meter readings should be repeated at each location until three consecutive readings are identical.*

Soil surface contacts with copper-sulphate half-cell electrodes give best results when the soil is moist. It is best, therefore, to remove any dry top soil until moist soil is exposed. Contacting the moist soil lowers the resistance in the meter circuit, which is equivalent to increasing the sensitivity of the instrument. Also, the contacts must be made *directly above* the pipe to avoid errors which originate from steep potential gradients in anodic sections disposed at right angles to the pipe line.

Any two copper-sulphate half-cell electrodes usually have a slight difference of potential, or this condition may develop during use, but this source of error can be compensated by alternating the electrodes in successive measurements.

Magnetic storms introduce errors in line-current and soil surface-potential indications in proportion to the storm-induced currents. These induced currents fluctuate and may even reverse in direction of flow. Surveys must be suspended during these disturbances, which may continue from a few hours to several days. The return of normal conditions can be determined from a millivolt recorder connected to the line for this purpose.

Recording the Survey Data

Graphic plotting of survey data is most useful because the relative conditions found by measurements and observations along a pipe line are thus better presented for interpretation and comparison. (See Figure 21, which shows the plotting of data taken at 100-foot stations over a period of several years.)

Maximum and minimum soil resistivities observed in each interval should be plotted to show soil variations in the increments. The successive interval data (see the lower two curves) will show the general soil variations along the pipe line.

Line-currents can be plotted in terms of current value. However, if the type of pipe (and therefore its resistance) along the line is uniform, plotting of the direct readings of millivolt potential drops for each interval will serve equally as well because the gains or losses of current are directly proportional to the observed potential drops.

Surface-potentials are plotted as converted pipe-to-soil potentials so as to show any abrupt changes between consecutive 100-foot stations. Two different scales are desirable for plotting pipe-to-soil potentials, one for measurements made with normal line conditions and the other for measurements after cathodic protection is applied.

Leaks should be recorded with reference to survey stations and if these leaks are segregated by years of occurrence, the resulting picture will assist in the interpretation of data from other sections where leaks have not occurred.

The measurement of the depth of the deepest pit or hole in each 100-foot section of previously surveyed lines which have been later raised for reconditioning will assist in the interpretation of data taken along unraised sections in the vicinity.

Plotting of other information pertinent to corrosion and to maintenance resulting from corrosion—such as coating, recoating and pipe replacement—will help in completing corrosion records.

Provisions should be made whereby all data taken at different times in the field will be properly reported as to location; otherwise the graphic record will not serve the purpose for which it is designed. This requires reference each time to the original line alignment surveys. Sometimes reference to telephone-post numbers will serve this purpose.

Editorial note: The foregoing is Part I of a Manual. The concluding portion of this manual will appear in the March, 1946, CORROSION.

Corrosion Protection by Phosphatization—A Review

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ONE OF THE METHODS used to inhibit the deterioration of metals is to convert the surface of the metal into a chemical compound of very low solubility in the environment to which it is to be exposed. This method may be considered a scientific imitation of similar, naturally occurring, processes, for example, the formation of an oxide film on aluminum. Oxide and phosphate coatings are examples of this imitation. Phosphate coats consist of gray, microscopic crystals of secondary and tertiary phosphates of various metals. The hardness, elasticity, tensile strength, and magnetic properties of the phosphatized material remain unchanged, but the coat of crystals acts as a porous blanket when oil, paint, or shellac is applied. The phosphate coat, when used alone, gives some protection against corrosion. However, the main protective value of the phosphate coat appears when it is used as a base for paint or similar substances.

Objects composed primarily of iron and steel are phosphatized by exposing them to a near-boiling phosphate solution for several minutes. The process is used widely in the automobile, typewriter, refrigerator, and similar industries. Following a description of the chemistry of phosphate rust-protection and its application an attempt is made to correlate the phosphatization process with another topochemical phenomenon, corrosion.

Chemistry of Phosphatization

Most phosphatization solutions contain one or more primary metal phosphates, free phosphoric acid, and an accelerator. These chemicals are dissolved in water to make a solution having a concentration of about two percent. The metal phosphates most commonly used are those of iron, manganese, and zinc. These chemicals, whose manufacture has been described in several patents (1), may be added to the solution in the form of a liquid syrup or a crystalline powder. In order to obtain a rust-inhibiting phosphate coat a homogeneous layer of secondary and tertiary phosphates, intimately bound to the surface, must be produced.

When iron or steel objects are immersed in a phosphatizing solution containing a primary, soluble, metal phosphate (M), some primary ferrous phosphate is formed by the reaction of iron with the free phosphoric acid in the phosphatizing solution. The primary salts subsequently react to form insoluble secondary and tertiary phosphates by one or both of the following types of reactions: (2,3)

(a) I. $M(H_2PO_4)_2 \rightleftharpoons MHPO_4 + H_3PO_4$
II. $AMHPO_4 \rightleftharpoons M_3(PO_4)_2 + H_3PO_4$
(b) I. $Fe + M(H_2PO_4)_2 \rightarrow FeHPO_4 + MHPO_4 + H_2$
II. $2FeHPO_4 + Fe \rightarrow Fe_3(PO_4)_2 + H_2$

The solution is held at such a concentration that the solubility products of the secondary and tertiary phosphates are not quite exceeded. When an iron or steel surface is dipped into such a solution there is a decrease in the hydrogen ion concentration at the metal-liquid interface owing to the following reaction:

III. $Fe + 2H^+ \rightarrow Fe^{++} + H_2$

This decrease takes place so rapidly at the interface that the solubility products of the secondary and tertiary salts are exceeded, and they are precipitated on the metal surface. Reactions (a) produce fresh hydrogen ions, and the original state of equilibrium thus tends to be reëstablished in the solution.

Hydrogen gas bubbles collect on the surface of the metal and almost prevent further action of the solution on the surface. In order to remove this hydrogen blanket a depolarizer (accelerator) is added in the form of an oxidizing agent. Thus the rate of formation of the phosphate coat is limited by the rate of the depolarizing reaction. The most widely used depolarizers are nitrates, nitrites, sulfites, and chlorates. Without these or other accelerators it takes six to eight hours for the formation of a phosphate coat on iron or steel. Through use of an accelerator this time is reduced to five minutes or less. Nitrates, nitrites, and sulfites have been found to be very good accelerators because they have such an oxidation potential that they readily oxidize hydrogen, but do not react with the ferrous ions to give insoluble ferric phosphates.

Properties of the Phosphatizing Solution

When iron goes into solution, as in reaction (III), in the form of ferrous ions in the presence of an oxidizing agent, some oxidation takes place, resulting in ferric ions. Mere contact with air may also bring this about. Ferric phosphates are insoluble and require much free acid to hold them in solution (6). In all phosphate coating solutions there is the choice of using more phosphoric acid than is necessary or desirable for coating purposes or of producing considerable quantities of sludge consisting primarily of complex phosphates containing ferric iron. It is necessary to keep the acid concentration (free acid) as low as possible because the hydrogen gas blanket is reduced to a minimum when the acidity of the bath is kept on a level that will be close to the acidity provided by the soluble primary phosphate.

Schuster and Krause (7) found that a zinc phosphate solution containing an oxidant (nitrate) had a lower rate of sludge formation than an iron or manganese phosphate solution. Phosphatizing solutions containing only iron phosphates are no longer used because they produce excessive quantities of sludge and give phosphate coats of low corrosion resistance (8). It has been found that in the zinc phosphate solution the amount of iron in solution increases from zero to a constant value when iron or steel is being phosphatized. Because the iron con-

tent remains constant, coats of uniform composition and corrosion resistance are obtained with this type of bath.

When the bath contains enough iron to produce precipitation (becomes milky), it is aged or "primed." To produce uniform coats of satisfactory corrosion resistance aged baths must be used. It is possible to reach this "primed" stage by phosphatizing until the solution becomes cloudy, but all articles phosphatized during this stage have poor coats. For this reason other methods are used. The solution may be aged by adding some cleaned iron scrap, steel wool, or a small quantity of iron phosphate solution.

Usually the cessation or a marked slowing of hydrogen gas evolution is taken to indicate the end of the reaction (9). Büttner (10) suggests that this is the case when the solution can no longer come into contact with the metal. Machu (11) advances the theory that the cessation of bubbling is not the end of the reaction, but that the phosphatization process stops when the remaining bare metal reaches a state of autopassivation. This stage is somewhat beyond the point where no more hydrogen is given off. The passive condition is determined by potentiometric measurements. In practice the process is not carried to completion but allowed to pass only through the initial, rapid stage extending to about fifteen minutes.

In order to control the bath the solution is analyzed for total and free acid concentration. The total acid concentration is given by titration with phenolphthalein indicator; free acid by using methyl orange (12). Macchia (13) suggests bromophenol blue in place of methyl orange for better results. The ratio of total to free acid (determined by titrating equal volumes of solution with the respective indicators) is often used in describing phosphatizing solutions. This ratio must be kept within definite limits (14). If the ratio of total to free acid is too low (free acid too high) treatment time is too long and the protective value of the coating is reduced owing to the decrease in tertiary salt content in the coat. If the free acid concentration is low, precipitation of insoluble phosphates will occur throughout the solution. If the absolute concentration of the bath is too low, the pH of the bath increases so rapidly in operation that precipitation of insoluble phosphates occurs throughout the solution. If it is too high, the pH is not increased rapidly enough at the interface and treatment time is too long.

Surface Pre-Treatment

The condition of the surface of the metal to be treated is of equal importance with the careful control of the chemical constituents of the phosphatizing bath. These two factors determine the character of the coat. The surface to be coated must be thoroughly cleaned to remove all traces of grease, rust, and scale. This may be done by vapor or solvent degreasing, acid and alkali cleaners, pickling, or by mechanical methods, such as sandblasting, grinding, polishing, brushing, and wiping.

Whenever possible, strong chemical action during cleaning should be avoided. Acid pickling and strong alkali treatment lead to a rapid consumption of the phosphatizing chemicals. The result is a coarse coat

(15) of low corrosion resistance, described by the trade as "sparkle," Figure 1. Pickling may more than double the time required for treatment (16). The best results are obtained when the objects are mechanically treated. Several authors have observed that wiping or brushing the surface before treatment greatly aids the rapid formation of a fine coat (17, 18, 19), Figure 2.

Jernstedt (19) has developed a pre-dip (following the cleaning operation) which gives the same results as mechanical brushing or wiping. The pre-dip consists of a hot solution of disodium phosphate and very small quantities of titanium ions (0.005-0.05 percent). It is thought that the cause of the "wiping effect" is probably the release or formation of an adsorbed film on the surface of the metal (20). Oxalic acid pre-dips were first used to produce this chemical wiping effect (21).

Copper or silver have been added in small quantities to phosphatizing baths as another means of accelerating the reaction (22, 23). The addition of copper to the bath is described in this section on surface pre-treatment because the copper is thought to act in a similar manner to pre-dips and mechanical wiping. The copper deposits as a fine film, which forms a galvanic element with the iron. The phosphate coats produced in this type of solution are rapidly formed and consist of very fine phosphate crystals interspersed with small particles of copper. The corrosion resistance of this type of coat is lowered by the galvanic couples produced by the copper particles, but the coat serves as an excellent base for paint.

The Phosphate Coat

The two outstanding properties of the phosphate coat are its ability to inhibit or delay corrosion of the underlying metal and its ability to absorb other coating materials in its pores. The fine, crystalline blanket is often harder than the underlying metal, for example ingot iron (24). Phosphatization, as has been mentioned before, does not change the hardness, elasticity, or magnetic properties of the treated material (25). Phosphatization of steel wire and ribbon causes some brittleness but does not affect the spring quality (26). The coat is an electrical insulator. The increase in dimension of phosphatized objects is near 0.005 to 0.01 mm. (25). This is not the thickness of the coat itself, because before the coat builds up iron goes into solution. Therefore the coat is actually thicker than the above dimensions would indicate.

Objects may gain or lose weight during phosphatization. It was found that the gain or loss in weight during the phosphatization of steel panels depends on the acid ratio of the bath and on the method of cleaning used to prepare the surface. For baths having a low acid ratio (high free acid concentration) there is a loss in weight (27). As the acid ratio is raised the loss in weight becomes less until finally the articles gain in weight. Surface treatment by acid pickling accentuates the loss or gain in weight. The changes in weight during phosphatization are found to vary between minus 0.020 and plus 0.005 gram per square inch (27).

Coats formed in a zinc phosphate bath on steel panels can withstand temperatures up to 600° F. without visible change. When heated above

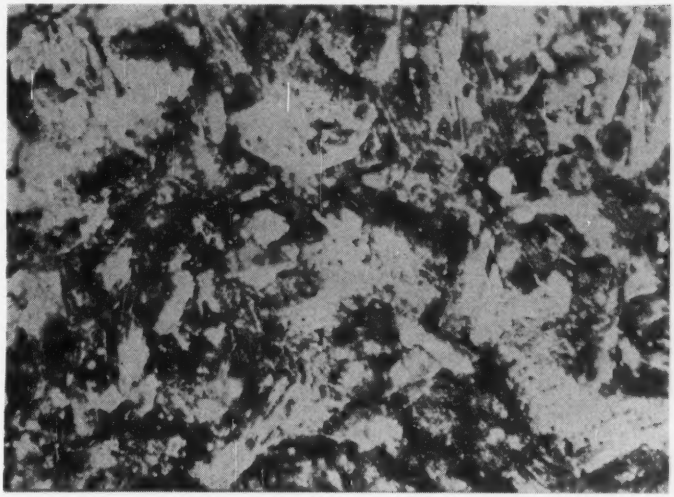

Figure 1—An example of "sparkle," the coarse phosphate coat photographed at 150X with a metallurgical microscope using direct and oblique illumination. The white areas represent the phosphate crystals.

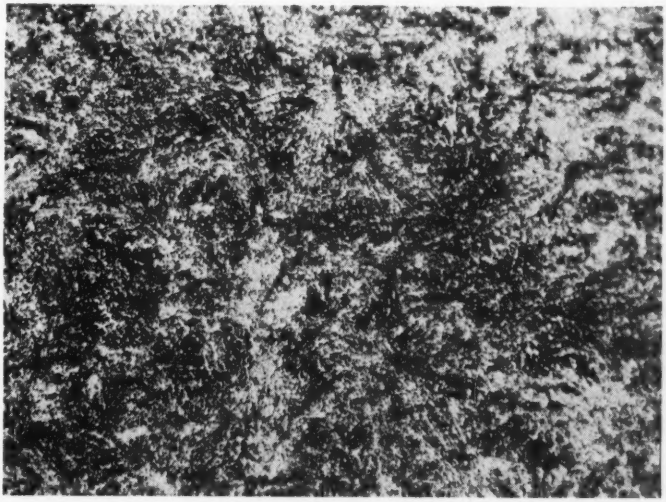

Figure 2—An example of a smooth, fine phosphate coat photographed under same conditions as figure 1. Magnification 150X.

this temperature, discoloration and peeling takes place (27).

To increase the corrosion resistance of phosphate coats they are often given a dip in a "passivating or sealing" solution immediately after removal from the phosphatizing bath and the rinsing tank. The solutions most frequently used contain the chromate radical (28). Oil, paint, shellac, waxes, and many other coating materials are readily adsorbed in the pores and together with the phosphate coat give excellent protection against a corrosive environment. When a painted surface, bonded to the metal with a phosphate coat, is broken and the underlying metal begins to rust, the corrosion attack will be confined to the break in the surface. There will be no creeping of rust under the coat of paint to cause peeling. Figure 3.

There are essentially two types of phosphate coats, the heavy, thicker coat, and the fine, paint-bonding type. The heavier coat is usually oiled or shellacked, while the light coat serves only as a base for paint. Phosphate coatings may be stripped from the base metal by a concentrated hydrochloric acid pickle or by immersion in a molten cyanide bath (29).

Phosphate coatings range from light to dark gray in color. The color of the coat depends on the underlying metal, the metal ions in the phosphatizing solution, and, within limits, the free acid concentration of the solution. A predominance of iron phosphates gives a darker coat, while zinc phosphate, if predominant, gives a light colored coat. Increasing the free acid concentration also darkens the coat.

The color of the phosphate coat may be changed by immersing the coat in solutions of certain dyes. Black coats are produced by coating with a layer of oil containing colloidal carbon. Another method consists of impregnating the crystalline surface with an aqueous solution of

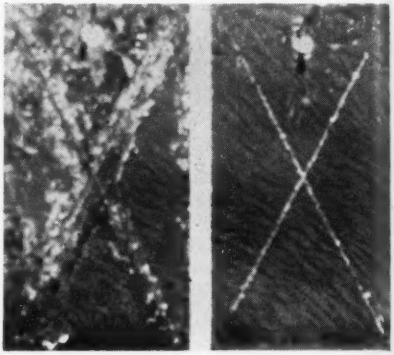

Figure 3—This photograph illustrates the effect of a phosphate base for paint. Panel at left received three coats of paint on cleaned metal surface. Panel at right was phosphatized before painting. Both were exposed to the salt spray after having been scratched in the form of an X. White areas are rust and bare metal. Salt spray duration was 250 hours.

a metallic salt which yields an insoluble gelatinous precipitate. The impregnated surface is then subjected to evaporation, cooling, heating, or chemical action, to precipitate the insoluble compound in the crystalline coat (30). For example, the coated article is first immersed in a solution of nickel acetate and then in a solution of dimethyl glyoxime. This produces a precipitate of nickel dimethyl glyoxime within the interstices of the coat and gives a scarlet color.

A large number of methods have been used to test the corrosion re-

sistance of phosphatized metals. Some of these are exposure to the atmosphere, salt-spray test, humidity test,, water-immersion test, heating test, immersion in sodium chloride solution, and mechanical bending and scraping tests (31). Of these only the salt spray has been used as a standard test (32). This method consists of exposing the phosphated surface to a fog made up of water-saturated air and a twenty percent sodium chloride solution at 96° F. Un-oiled phosphatized surfaces are usually expected to show no signs of rusting after three hours of exposure in the salt-spray tank, and 24 hours if oiled. Paint adhesion is tested by making a scratch through the paint and phosphate coat down to the metal. On exposure to the salt spray for 250 hours the rust formed in the scratch should not creep more than one-eighth of an inch away from either side of the scratch to pass the standard requirements.

Baker (33) and associates found that various methods of corrosion testing of phosphate coats gave nearly identical results. The salt-spray test gave the most sensitive results, immersion in distilled water and 0.01 N sulfuric acid were less sensitive, and 5 to 20 percent sodium-chloride solution immersion tests were unreliable.

The presence of certain metal ions in the phosphatizing solution prevents the coat from adhering rigidly to the metal, thus causing smudgy coats which wipe off. Lead and arsenic are the most outstanding of this group. Macchia (34) has found that if arsenic is present in a concentration greater than 0.005 percent the phosphate coat will smear.

Industrial Application

The objects to be coated must be cleaned, rinsed, phosphatized, rinsed again, and dried. If pre-dips and sealing treatments are used these follow the rinsing operations. Various mechanical methods have been developed to carry out these operations. The oldest apparatus consists of a series of heated tanks connected by an overhead trolley which is used to move the objects from one tank to the next. For continuous operation on a large scale a spray process has been developed. The process is used primarily for paint-bonding coats which require only a relatively thin layer of crystals. Machinery for this purpose has been designed on the assembly line principle (35). The articles, such as automobile fenders, doors, and hoods, move through a series of spraying chambers in which they are cleaned, rinsed, phosphatized, rinsed again, and dried. The applicability of the phosphatization process to the assembly line has given a tremendous impetus to the large scale use of the process as a paint bonding method.

The largest use of phosphate coatings is a base for paint. The next most important use is as a finish for tools and machine parts. Some use is made of phosphate coats for cold drawing operations. When phosphatized iron bars are drawn through a die the phosphate crystals are crushed and ground with the lubricant to form a plastic mass (36). Phosphate coats make drawing easier, chiefly through their adsorptive powers for lubricants and their high plasticity. Phosphate coats impregnated with graphite improve the running-in properties of piston rings (37).

Corrosion and Phosphatization

The corrosion of metals may be described as the unintentional changes caused by chemical action of their environment on their surface, which result in their deterioration or destruction. The metals tend to revert to more stable combinations, such as those found in metallic ores. The chemical changes taking place during corrosion are heterogeneous, topochemical reactions (38). Not only the purely chemical reaction is of importance in corrosion but also the nature of the surface and the solid corrosion products.

Speller (39) gives reactions for a simple case of the corrosion of iron. The primary reaction

1. $Fe + 2\ H^{+} \rightleftharpoons Fe^{++} + 2H$

is followed by either

2. a. $2H + \frac{1}{2}O_2 \rightarrow H_2O$
or b. $2\ H \rightarrow H_2$

These reactions produce an accumulation of ferrous ions in the solution which are oxidized to form rust.

3. $Fe^{++} + \frac{1}{2}O_2 + H_2O \rightarrow 2Fe^{+++} + 2OH^{-} \rightarrow Fe(OH)_3$ (rust)

Walker (40) pointed out that the depolarizing reactions No. 2 are the limiting reactions in the series. (Compare with the limiting reaction of the phosphatization process.)

The phosphatization process may be considered a form of "controlled corrosion." Small quantities of the metal being coated dissolve (corrode) with the evolution of hydrogen. To permit this reaction to continue the hydrogen must be removed in both the phosphatization and corrosion processes by a depolarizer (oxidizing agent). During phosphatization the dissolution of iron causes supersaturation of metal phosphates in the solution near the surface of the metal and crystallization takes place. A crystalline coat is formed which eventually prevents further dissolution of the metal and the "corrosive process" is stopped.

During the corrosion of uncoated iron the destructive reaction continues as long as hydrogen is removed, because the solid products (rust) formed do not give an adherent coat. Since the coating is not adherent, scaling exposes more fresh metal, the attack is renewed, and the metal gradually deteriorates.

Historical Note

The first example of phosphate rust protection was found in Homburg, Germany, among Roman ruins dating back to the third century (41). Iron objects covered with a layer of blue-green hydrous ferrous phosphate (vivianite) were discovered. There is some question as to whether this layer was formed accidentally by contact with nearby bone ashes or whether the coat was applied with knowledge of its properties. The first patent on phosphate rust protection was taken out by Ross in 1869 (42). Red-hot iron objects were dipped in phosphoric acid to increase their resistance to oxidation and perspiration.

Thomas W. Coslett of Birmingham, England, was the first to make the phosphatization of iron and steel industrially applicable. In a series of patents beginning in 1906, Coslett described his process. He suggested that the free acid content should be kept as low as possible, that the coat should be oiled or otherwise

coated to increase further the corrosion resistance, that an electric current should be used to accelerate the reaction, and that addition-agents (borates) should be used to reduce the time required for phosphatization (43). Coslett may be considered the originator of industrial phosphatization. His work is the basis of phosphate rust protection as it is known today.

Acknowledgment

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Notes on Use of Copper-Nickel Alloy in HF Alkylation Processes

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A SERIES of tests as well as observations from operating equipment in HF alkylation service indicate that a copper-nickel alloy (approximately two-thirds nickel and one-third copper) has emerged as possibly the most useful of commercial materials to resist the corrosion from HF (hydrofluoric) acid. This copper-nickel alloy and its variations are used as liners for vessels, as rings and packing, and for valves and fittings. Table I gives the approximate analyses of these alloys and Table II shows some data on their resistance to various strengths of hydrofluoric acid.

In some cases there has been a tendency to use these alloys as lining for towers that are packed with

TABLE I

Approximate Compositions of Copper Nickel Alloys

MATERIAL	Nickel Per Cent w	Copper Per Cent w	Iron Per Cent w	Aluminum Per Cent w	Silicon Per Cent w	Manganese Per Cent w	Carbon Per Cent w
Copper Nickel Alloy (Monel)	67	30	1.4	....	0.1	1.0	0.15
Silicon Copper Nickel Alloy ("S" Monel)*	63	30	2.0	....	4.0	0.9	0.1
Aluminum Copper Nickel Alloy ("K" Monel)	66	29	0.9	2.75	0.25	0.4	0.15

* Only as castings.

TABLE II

Corrosion Tests (Air-Free)

Copper-Nickel Alloys in Hydrofluoric Acid

MATERIAL	Acid Conc. Per Cent w	Temp. Deg. F.	Agitator Gas*	Time Days	Area† Dm_2	Corrosion Rates	
						Mdd‡	Ipy§
Copper-Nickel	25	86	Nitrogen	6	0.50	1.0	0.0002
Alloy (wrought)	25	176	Nitrogen	6	0.50	14.5	0.0024
(Approx. 69% Ni	50	86	Nitrogen	6	0.50	0.4	0.0001
29% Cu)	50	176	Nitrogen	6	0.50	3.6	0.0006
Copper-Nickel	25	86	Nitrogen	6	0.13	3.5	0.0006
Alloy (cast)	25	176	Nitrogen	6	0.13	8.3	0.0014
(Approx. 69% Ni	50	86	Nitrogen	6	0.13	2.8	0.0005
29% Cu)	50	176	Nitrogen	6	0.13	13.5	0.0022
Silicon—Copper—Nickel	25	86	Nitrogen	6	0.30	1.5	0.0002
Alloy (cast)	25	176	Nitrogen	6	0.30	1.1	0.0002
(Approx. 4% Silicon)	50	86	Nitrogen	6	0.30	2.3	0.0004
	50	176	Nitrogen	6	0.30	12.1	0.0020

* Agitation Rate = 100 cc/min.
† Dm_2 = Square decimeter.
‡ Mdd. = Milligrams per sq. decimeter per day.
§ Ipy. = Inches penetration per year.

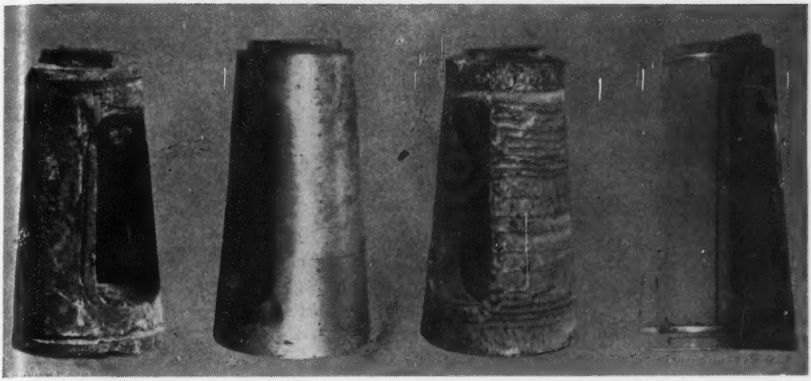

Figure 1—Four stages in the repair of the steel plug of a valve used in HF alkylation plants. At the left is a plug as pulled from service and requiring reconditioning. Adjacent is a similar plug, machined undersize for overlay of new metal. The third plug shows the manner in which the turned plug is overlaid with copper-nickel alloy, while the plug at the right has been finished, machined, ground and lapped, with lubrication grooves restored.

carbonaceous material. A study of the effects of carbonaceous material when acting as cathodes will be made the subject of a further contribution to this journal. At this point it can be said that the carbonaceous packing material would probably accelerate the corrosion of a copper-nickel alloy liner, or for that matter of any other metal.

In the matter of valves, a high silicon (4 percent Si) variation of this alloy has been found very useful for cast plugs in HF alkylation units, because of its non-galling properties. This alloy is available only in cast form. A high-silicon copper-nickel rod has been developed that permits an overlay of this alloy on other plug material. The

TABLE III

Corrosion Tests (Air-Saturated vs Air-Free)
Copper-Nickel Alloy in Hydrofluoric Acid

MATERIAL	Acid Conc. Per Cent w	Temp. Deg. F.	Agitator Gas*	Time Days	Area† Dm_2	Corrosion Rates	
						Mdd‡	Ipy§
	25	86	Air	1	0.50	230.0	0.0380
	25	86	Nitrogen	6	0.50	1.0	0.0002
Copper—Nickel Alloy (wrought) (Approx. 69% Ni 29% Cu)	25	176	Air	1	0.50	67.0	0.0110
	25	176	Nitrogen	6	0.50	14.5	0.0024
	50	86	Air	1	0.50	48.7	0.0079
	50	86	Nitrogen	6	0.50	0.4	0.0006
	50	176	Air	1	0.50	241.0	0.0400
	50	176	Nitrogen	6	0.50	3.6	0.0006

* Air agitation rate = 300 cc/min. Nitrogen agitation rate = 100 cc/min
† Dm_2 = Square decimeter.
‡ Mdd = Milligrams per square decimeter per day.
§ Ipy. = Inches penetration per year.

use of this overlay has facilitated the repair of valves for use in HF service. See Figure 1.

Some hesitancy was experienced in using the high-silicon forms in HF service due to the thought that the silicon would be attacked by the acid. Experiments have demonstrated that this uneasiness is not warranted. The experiments indicate that the rate of corrosion of the copper-nickel allows containing silicon is no more vigorous than can be expected from the regular grade, which is low in silicon, and which is notably resistant to HF. It is apparent that while silicates are attacked, metallic silicon is not subject to special attack by HF acid.

A problem has arisen involving bolts for use in valves handling HF acid and material contaminated with this acid. The most satisfactory solution at the moment for the breakage of the steel bolts appears to be to make use of an aluminum-copper-nickel alloy in the hot-rolled and aged condition. In this condition the metal gives the following mechanical properties:

Tensile Strength	140,000—165,000 psi
Yield Strength	100,000—125,000 psi
Elongation in 2"	20 percent

The success of above uses of the copper-nickel alloys is dependent upon comparatively air-free conditions. Table III shows the effect of air on the corrosion rates.

Corrosion Abstracts

FUNDAMENTAL INFORMATION

Rate of Corrosion and Electrode Potentials of Magnesium As Affected by pH of the Solution. G. V. AKIMOV and I. L. ROSENFELD, Comp. rend. (Doklady) Acad. Sci. (USSR), **44**, No. 5 193, (1944) (In English) J. of Inst. of Metals and Metall. Abs. **12**, 114 (1945) April.

Electrode potentials and rates of corrosion of magnesium specimens were measured in hydrochloric acid, distilled water, and sodium hydroxide, from pH 2 to pH 8 both potential and corrosion rates are high, but decrease sharply. There is no protective film in this region. From pH 8 to pH 11 the electrode potential remains constant, but the rate of corrosion falls steadily. This behavior is connected with the formation of a protective film and its growth as pH increases. From pH 11 upwards the film increases sharply.

Formation and Structure of Iron Oxide Films. V. I. ARKHAROV, et al., J. of Tech. Physics (USSR), **1944**, No. 14, 132 (In Russian) Iron Age, **156**, No. 3, 65 (1945) July 19 (Translation).

The crystal structures of iron, nickel and cobalt oxide films were studied by X-ray reflection and are reported. Oxidation of nickel in air at 2282° F. produces a film consisting of nickel oxide only. The nickel oxide phase contains almost no holes and the higher spacing near the film-air interface seems to be due to incorporation of some oxygen atoms into the nickel oxide lattice, which diffuse toward the metal and form nickel oxide crystals at the metal surface. Thus the nickel oxide film grows only from the metal side. The ferrous oxide was found to build up along its two faces. Rate of oxidation of nickel is less than that of iron since the gradient of spacing across the oxide film is smaller. Cobalt behaves similarly to nickel. From the examples of all three metals, an important rule is drawn: The oxidation of a metal in air proceeds the more rapidly, the steeper the spacing gradient within the oxide film.

CORROSION TESTING

Alternate-Immersion Test for Aluminum-Copper Alloys. R. B. MEARS, C. J. WALTON AND G. G. ELDRIDGE, Aluminum Co. of America, A.S.T.M. Proc. **44**, 639 (1944).

The Aluminum Research Laboratories alternate-immersion test is discussed in detail. Consideration is given to (1), a complete description and method of conduction tests; (2), results of corrosion tests on internal standards and laboratory heat-treated material; (3), effect of variation in concentration of solution; (4), effects of change in volume of solution per unit area; change in thickness of specimen, method of surface preparation, and duration of exposure. The test solution is composed of 57 g. sodium chloride and 3 g. hydrogen peroxide per liter. The test is set up

so that the solution bath is raised and lowered to give alternating immersion.

A Variable-Cycle Alternate-Immersion Corrosion-Testing Machine. C. H. MAHONEY, Basic Magnesium Corporation, A. L. TARR AND K. A. SKEIE, A. S. T. M. Bull. **133,** 16 (1945) Mar.

This machine tests up to 48 specimens in separate glass solution containers which are treated in a common bath. Immersion and aeration periods are automatically controlled by means of independent time switches.

Corrosion Resistance of Clad 24S Aluminum Alloys. C. M. MARSHALL, Consolidated Vultee Air Craft Corp., Automotive and Aviation Ind. **93,** No. 1, 28 (1945) July 1.

The results of tests during which clad 24S, both aged and un-aged, was exposed to a salt spray solution for 500 hours, and to an accelerated corrosion medium containing salt and hydrogen peroxide for a 48-hour period indicate that the yield and ultimate strengths of both types were not affected by either of the corrosive solutions. Surface pits were noticeable on both samples in salt spray test. Unprimed, un-aged samples showed slight attack along grain boundaries in accelerated corrosion media. A zinc chromate base prime coat prevented this attack.

Report of Subcommittee II on Performance Tests; Electroplated Lead Coatings on Steel. A. S. T. M. Proc. **44,** 280 (1944).

This committee initiated atmospheric exposure tests of electro-plated lead coatings on steel. The purpose of the tests is to determine the effect of lead thickness, the type of plating bath, the presence or absence of a thin copper undercoating, and of physical damage to the coating on the useful life of such coatings in various atmospheres. Stations were selected to represent industrial, rural, sea-coast and tropical atmospheres; 148 panels were set up at each station. All panels were prepared in the same manner. Preliminary results are reported but shortness of exposure does not warrant broad conclusions regarding the utility of electroplated lead coatings at this time.

Report of Subcommittee VI on Atmospheric Corrosion Tests of Non-Ferrous Metals and Alloys. A.S.T.M. Proc. **44,** 224 (1944).

This is a continuation of the 1943 report on the results of the ten year atmospheric exposure tests conducted at seven stations on 24 non-ferrous metals. The seven stations included industrial or semi-industrial, sea coast and rural. "Graded summaries" are given which show the changes in material, such as loss in weight, average penetration, and changes in tensile strength.

Basic Requirements in the Standardization of the Salt Spray Corrosion Test. L. J. WALDRON, A. S. T. M. Proc. **44,** 654 (1944).

Basic requirements should be such that the samples will be exposed at a constant temperature to a uniformly distributed dense fog of constant, known composition. It is felt that specification should also include preparation, positioning and inspection of samples. A detailed discussion

of temperature control, composition of salt solution and standardization is included.

Anti-Freeze Solutions. E. W. STEINITZ, C. R. Laboratories, Automobile Engineer, **35**, No. 460, 123, (1945) March.

Among tests of fluids for liquid-cooled internal combustion engines, corrosion tests are described. Mild steel, copper-iron jointures, copper and aluminum were tested in various concentrations of anti-freeze and ethylene glycol. A variety of methods for testing is described. In one, a glass vessel containing all the materials used in an actual system are kept in metallic contact with each other, since in new motor-car models all metal parts are connected to keep down corrosion. In another, a test-stand consists of a cylinder block of cast iron, a cylinder head of aluminum-silicon alloy, a water pump of all cast iron with bronze impeller wheel, driven by an electric motor, and a small radiator. This method proved superior to chemical laboratory methods. The test rig simulating conditions in a car and corrosion test in progress in a Thiele tube are shown. Corrosion data are tabulated, as well as materials used for various parts of engines.

CHEMICAL CORROSION

Resistance of Chromium-Nickel Austenitic Steels to Nitric Acid. A. GOTTA, Korrosion und Metallschutz, **17**, No. 7, 241 (1941).

The resistance of 18-8 steel containing 0.1 percent silicon to boiling fuming nitric acid is much higher than that of the same steel containing 0.5 percent silicon. It may be expected that low silicon, or still better, silicon-free acid-resisting 18-8 steels when used in apparatus subjected to especially severe action of nitric acid and nitrogen oxides will show a much longer useful life than 18-8 steel with some tenths of one percent of silicon.

Corrosion Reporter. Chem. and Met., **52**, No. 3, 172 (1945) March.

Manufacturers interviewed discussed the following: use of stainless with nitric acid, as well as Tygon and Tygon paint; use of stainless and Pyrocast for mercury nitrate at 400° C.; use of Elcomet K pumps and castings, Everdur or copper piping, zinc-free bronze for pipe fittings and Monel for centrifuge parts, baskets and shaftings with oxalic acid; use of tellurium lead with sulfuric acid (found not better than chemical lead); materials used in manufacture of chromates and bichromates. In the latter, where variable solutions of chromic acid and sodium bisulphate are handled up to 100° F., Durimet and 18-8 are used. the latter only where 2 percent of chromic acid is present as an inhibitor. Monel evaporators are employed after the bichromate is removed. Centrifuges and driers are lined with Monel or 18-8 stainless. Mercuric chloride viciously attacks all metals, even when powdered product is apparently dry. Glass and chemical stoneware are the only usable materials, although it has been said that tantalum may be a possible solution.

CATHODIC PROTECTION

The Use of Zinc for Cathodic Protection. H. W. WAHLQUIST, Ebasco Services, Inc., Corrosion **1**, 119 (1945) Sept.

The use of zinc as a current source in cathodic protection has a number of advantages where soil conditions are favorable. These include a cost advantage, adaptability in highly anodic sections, and ease of application in congested areas. Lack of knowledge of the long time behavior of zinc in various soils has been a severe handicap to the efficient use of zinc. This paper presents information collected in a comprehensive study of the behavior of zinc anodes in Colorado and in Houston, Texas. The study includes detailed study of the soils, effect of polarization, record of frequent checks on potential changes, and an extensive research project on backfill materials.

Zinc Anodes for Preventing Corrosion of Distributing Mains. C. L. MORGAN, United Gas Corporation, Petr. Eng. **16,** No. 13, 196 (1945) Sept.

History of the development of the use of zinc anodes for cathodic protection of the gas lines of the city of Houston. It includes the leak record before and after installation of zinc anodes. The design and installation of anodes are discussed along with the problem of insulating lines from surroundings. Cost and performance of these installations are also presented.

Light Metals for the Cathodic Protection of Steel Structures. R. B. MEARS AND C. D. BROWN, Aluminum Company of America, Corrosion **1,** 113 (1945) Sept.

Laboratory data are presented to show the favorable position of aluminum in the application of light metals in the field of cathodic protection. Short-time field experiments appear to substantiate the laboratory data where a backfill of clay plus 5 percent sodium chloride and 5 percent lime is used.

Electrical Process Prevents Corrosion. Steel, **116,** No. 15, 122 (1945) April 9.

Corrosion is prevented on the inner surface of a steel water-storage tank by a new automatic electrical method based on maintenance of an electrical potential between steel water-storage tank shell and water in contact with the surface. Current is adjusted in amount sufficient to maintain ionized hydrogen film on inside surface of the tank. Film acts as an insulator, protecting the iron from contact with the water and action resulting in partial dissolution or corrosion. This system removes old rust and corrosion and eliminates need for scraping and painting the inside wall.

Cathodic Protection of Steel Surfaces in Contact with Water. LEON P. SUDRABIN, Electro Rust-Proofing Corp., W. W. and Sewerage, **92,** R-67 (1945) Je.

An extensive review covering: (1), the basic principles and controlling phenomena involved in using cathodic protection for mitigation of water corrosion; (2), comments on the practical application of this process; and (3), its applications to hot water tanks, clarifier mechanisms and deep wells. 44 references.

CONSTRUCTION MATERIAL

Corrosion Reporter—Materials Used in Producing Chemical Colors. Chem. and Met., **52,** No. 7, 187 (1945) July.

A condensed summary is offered of materials used in producing chemical colors by a leading producer. A flow-sheet shows arrangement of equipment, while parts and materials are tabulated. Stainless stell is used in various fittings for use with sulphuric, nitric and chromic acids.

Fluorine Industry Molds a Post-war Career from Wartime Service. J. R. CALLAHAN, Chem. & Met. Eng. **52,** No. 3, 94-99 (1945) March.

A survey of the fluorine industry, giving process, history, principal producers, manufacturing flow chart, uses, and materials of construction which are acceptable in its manufacture. Monel is comparatively excellent or satisfactory. Valves, stirrers, rotary drier liners of Monel are described. The life expectancy of the stirrers is only ½ month. Corrosion studies are under way at the Easton works which may modify design and life of some equipment. Postwar prospects for Freon are promising, both as a refrigerant and as a propellant for aerosol insecticides. Production statistics of anhydrous HF are given. Platinum, one of the most resistant of metals to hydrofluoric acid, and silver have excellent resistance to it in the absence of sulphides or of appreciable amounts of sulfuric acid.

REFINERY CORROSION

Corrosion of 18-8 Alloy Furnace Tubes in High-Temperature Vapor Phase Cracking Service. E. J. CAMP AND CECIL PHILLIPS, Humble Oil and LEWIS GROSS, Taylor Refining Co., Corrosion **1,** 149 (1945) Sept.

Rapid failure of 18-8 alloy furnace tubes in processing naphtha from sweet Refugio crude made a butadiene plant inoperable. Tubes failed in from 120 to 400 hours of service by reason of uniform thinning of tubes. Comparison of properties of feed and products with those of a similar plant revealed the absence of mercaptan sulfur in the Taylor Plant. Investigation showed that this corrosion could be practically eliminated by adding small quantities of sulfur to the feed stock. The cause of the corrosion was not determined.

The Corrosion Resistant Characteristics of Some Condenser Alloy Tube Alloys. A. W. TRACY, American Brass Company, Corrosion **1,** 103 (1945) Sept.

A discussion of the properties and characteristic attack of copper alloy tubes in refineries and power plants is discussed. Dezincification type of attack may be general as in acid water or plug type as found in alkaline waters. Addition of inhibitors reduces attack. Impingement corrosion results from turbulent action which continuously remove the protective film. In sea water 30 percent cupro-nickel has proven best. Stress corrosion in refineries is usually associated with moisture, oxygen and ammonia. Fatigue type attack is observed under conditions of excessive vibration. The general properties of deoxidized and arsenical coppers, red brass, Admiralty, aluminum brass, cupro-nickels, and aluminum bronze are given.

Corrosion Problems in the Petroleum Industry. The Action of Protective Films. A. H. STUART. Petroleum (London) 128 (1945), July.

Investigations of the electrical insulating properties of enamel and lacquer films showed that a large number of these, although good insulators when dry, possessed an appreciable de-

gree of conductivity when wetted by an electrolyte, allowing the passage of the ions of iron from the metal to the water. Under the conditions of the test, plain steel, dipped in a synthetic resin, showed a readily visible film of rust in 6 hours, and after 72 hours showed several small specks of red rust which would have developed at an increasing rate. It was concluded that, although the film would not prevent corrosion, it would substantially reduce the rate at which rust would form. Similar electrical tests indicated that even the most favorable oil and grease films also break down under certain conditions. Anti-corrosion oils which have an attraction for water have now been developed. These are readily self-emulsifying and any condensation of moisture is quickly absorbed by the oil and does not reach the coated metal.

From the practice of marking products from the rolling mill with batch numbers by means of red-lead paint while the iron is still hot, it was discovered that these batch numbers resist corrosion for long periods while the same paint applied over the mill scale after the iron is cold affords very little protection. This is explained by the fact that the paint, if applied while the iron is still hot, is still sufficiently fluid to flow into the interstices when cracking of the iron takes place thus excluding air and moisture. However, if the paint is not applied until the iron is cold, corrosion cells are set up under the paint film, as the cracks are already formed and filled with moist air. It has been suggested that it would be beneficial to dip the plates and sections into a bath of linseed oil carrying a red-lead or other anti-corrosive pigment as they leave the mill or at least before they cool off.

Glue, starch, phenol and thiourea are mentioned as inhibitors to reduce the risk of the sulfuric acid (used in pickling for removing mill scale) attacking the iron sufficiently to form nascent hydrogen, thus making the iron brittle.—Lib. Bull. of Abs., Universal Oil Products Co.

SURFACE TREATMENT

Phosphating at Room Temperature. L. SCHUSTER AND R. KRAUSE, Korrosion und Metallschutz, **20,** No. 5, 153 (1944), May.

The factors playing a role in the development of phosphating systems that produce coatings at room temperature are described and their influence on the formation of the coatings explained. The cold bonderizing process, a fast process applicable both by spraying or dipping, in commercial use for more than three years for purposes of rust-proofing and cold forming, is described with special reference to the differences from the hot phosphating processes. A brief outline of the advantages of cold phosphating and the most important properties of coatings obtained at room temperature from zinc phosphate solutions has been presented. The many applications of cold phosphating are pointed out.

COATINGS

Corrosion Preventives, New Type Petroleum Preservatives Developed to Protect Equipment During Storage and Transportation, C. M. LARSON, Sinclair Refining Co., Nat. Petr. N. **37,** R 609 (1945) Aug. 1.

Choice of rust preventive depends on: (1), nature and function of parts surfaces; (2), type of exposure anticipated and degree of preservation; (3), ease of application; and (4), availability. A series of evaluation

tests is discussed, specifications of several army and navy grades of rust preventives are given, and procedures for application are listed and discussed.

New Developments in External Coatings and Corrosion Preventive for Canned Foods. H. R. SMITH, proc. Inst. Food Tech. (1944), 26.

Solid waxes, water emulsion waxes, solvent waxes, petroleum products, paints and alc. sol, resin lacquers were tested by means of the continuous salt spray exposure tests of the Bureau of Standards and by simulated field conditions to ascertain their efficacy as external rust preventives for tin cans. The paints were most satisfactory in preventing rust and in providing camouflage. The solid waxes gave protection but were difficult to apply. Coating by dipping and by spraying were effective, but dipping is generally simpler and less costly in common practice. Water-emulsion waxes were protective, but difficulties are incorporating. Sufficient pigment to provide camouflage were encountered. Paper labeled cans exhibited the greatest corrosion due to moisture being retained. Tables are presented evaluating numerically the various preventives tested. Commercial-coating problems and Quartermaster Corps specifications are discussed.

Corrosion Preventives. J. R. C. BOYER, E. F. Houghton and Co., Steel 116, 128 (1945) June 11.

Paper covers removable coatings which include solvent type, grease or petroleum type, oil type emulsified grease type, and plastic stripping type. Protection expectancy is predicted for the various coatings under numerous conditions. Guide for selecting proper coating is given.

Corrosion-Proofed Metals. Plastics **3,** No. 1, 98 (1945) July.

A phenol formaldehyde resin, called Protect-O-Phene and developed by Poly Resins Co., is reported as being highly abrasion resistant, withstanding considerable heat and being easy to apply. Application consists of brushing, dipping or spraying and heat treating at 275° for pre-coats and 350-400° for final coat. Coating is resistant to strong chemicals such as 50 percent sulfuric acid and zinc chloride solutions. The coating is very flexible, as is shown by its application to coiled springs.

Zinc Chromate Primers vs. Corrosion. W. R. BARRETT, Reichhold Chemical, Inc., Organic Finishing, 6, No. 3, 17-19 (1945) March.

A combination of the following reasons explain the efficacy of zinc chromate primers in inhibiting corrosion: (1), the zinc chromate primer film itself retards diffusion of oxygen to the metal surface; (2), the soluable chromate ions liberated when zinc chromate is dissolved in water act as an oxidizing agent and change the soluble ferrous hydroxide coating to the more insoluble ferric hydroxide film; (3), the zinc chromate primer films tend to buffer the solution at a pH of about 7, representative of the range where ferric hydroxide is stable and relatively insoluble; and (4), the zinc ion liberated may act as a polarizer, preventing liberation of nascent H and hence causing passivation. The two most prominent current zinc chromate specifications are discussed. By combining zinc yellow with a wide variety of binders, zinc chromate primers of almost any desired group of performance characteristics may be obtained.

Protective Painting of Structural Steelwork. J. C. HUDSON, J. of the Oil and Colour Chemists Assoc., **28,** 27 (1945) Feb. Bull of the Iron and Steel Inst., **112,** 159A (1945) April.

The paper on the protective painting of structural steel by the Protective Coatings Sub-Committee of the Corrosion Committee is reviewed and amplified by more detailed references to the experimental work of the Corrosion Committee of the Iron and Steel Institute.

Synthetics and Engineered Corrosion Control. D. F. SIDDALL, Monthly Rev. Am. Electroplaters Soc. **32,** 331 (1945).

A discussion of corrosion and its control, in particular by the use of protective organic coatings. C. A. **39,** 2725 (1945).

Polyisobutylene Tank Lining. D. W. YOUNG AND W. C. HARVEY, Standard Oil of New Jersey, Ind. & Eng. Chem. **37,** 675 (1945) July.

This polymer resembles slightly broken down rubber and is an aliphatic hydrocarbon that is essentially non-reactive at temperature up to 100° C. in caustic or acid solutions. Method is proposed for preparing tank lining from this material. Suggestions are made for preparing polymer for lining and procedure for application. The bond strength of the liner and detailed data on its resistance to many chemicals are given.

GAS AND CONDENSATE CORROSION

NGAA Condensate Well Corrosion Studies, Petr. Eng. **16,** No. 13, 277 (1945) Sept.

National Gasoline Association, on entering its second year of intensive research program, announces three additional studies which are sponsored by the NGAA Corrosion Research Project Committee at the University of Texas. Dr. Norman Hackerman is directing a study of surface film on well equipment. Dr. H. L. Lochte is directing a project concerning the varieties and concentrations of organic acids and other compounds, such as phenols, in water taken from condensate wells. Dr. W. A. Cunningham has a project covering routine analyses of water samples from corrosive and non-corrosive wells. Studies to date have shown carbon dioxide and organic acids to be contributing factors. A satisfactory analytical procedure for quantitative determinations of the amount of organic acids present in well-head waters has been perfected and is now being used in field surveys. Investigations have also been made of the effect of electrostatically charged particles in high pressure gas streams, using an instrument developed for the committe by Battelle Memorial Institute, and a series of field experiments is now in progress. Quantitative information on rates of corrosive attack on various kinds of alloys has been obtained. U. S. Bureau of Mines is studying laboratory and field studies of corrosive materials, resistant alloys, corrosion inhibitors and phase distribution in flowing wells. N.A.C.E. under direction of Walter F. Rogers is testing various alloys in the gas streams of corrosive wells.

Corrosion Resistant Sucker Rods. Corrosion **1,** 148 (1945) Sept.

The successful application of nickel-coated sucker rods in a West Texas oil field is reported. A hardenable aluminum-copper-nickel alloy is re-

ported as being in a corrosive service without apparent attack for 4 years.

BEARING CORROSION

Diesel Engine Bearings, Discussion of Failures and Progressive Inspection Measures. L. M. TICHVINSKY, American Bearing Corporation, Mech. Eng. **67,** 297 (1945) May.

The object of this report is to describe common Diesel engine bearing operation and failures, and to indicate rational bearing maintenance methods. The following causes of failure are discussed: (1), fatigue of bearing metal under high cyclic loads; (2), excessive or insufficient hardness of the bearing metal; (3), corrosion of the bearing metal by the lubricating oil; (4), inadequate bond between bearing metal and bearing shell; (5), assembly errors; (6), foreign particles. Article is well illustrated with normal and microphotographs.

ALUMINUM CORROSION

Inhibitors of Corrosion of Aluminum. G. G. ELDREDGE AND R. B. MEARS, Aluminum Research Laboratories, Ind. & Eng. Chem. **37,** 736 (1945) Aug.

A review, including new data, of the use of inhibitors in controlling the corrosion of aluminum. Chromates are effective in phosphoric acid but not in hydrochloric or sulfuric. Nitrogen compounds are more effective in hydrochloric than phosphoric acid. Chromates, silicates and soluble oils are effective in water. Water serves as an inhibitor in some newly anhydrous organic chemicals. Chromates are effective in alcohol solutions.

Influence of Over-aging on Aluminum Alloys, Iron Age **156,** 66 (1945) July 19.

Data are reported on results of tests conducted on high strength aluminum alloy sheet to determine the effects of over-aging on physical and corrosion inhibiting properties. The aging tests involved heating of specimens for 24 hours at 250, 375 and 450° F. Test specimens from each lot were over-aged at 375° F. for 100, 400, 600, and 1000 hours. Test specimens were corroded chemically and then subjected to the Southwark-Emery testing machine. There was little difference between the mechanical properties of corroded and uncorroded specimens, however all specimens aged above 250° F. were severely affected.

Further Observations on the Protective Influence of Manganese in the Corrosion of Aluminum Containing Magnesium Alloys — Paper 992. F. A. FOX AND C. J. BUSHROD, J. of Inst. of Metals, **71,** Pt. 5, 255 (1945) May.

Alloys containing 8 percent aluminum, 0.5 percent zinc, 0.25 percent manganese, balance magnesium, and varying iron contents from 0.024 to 0.001 percent (DTD Spec. 59A) were tested in sodium chloride (3 percent) solution and in the atmosphere in cast, solution-treated and fully heat-treated condition. Specimens were small cylinders machined from ingots. When manganese is 0.2 to 0.3 percent, variations in iron regardless of structural conditions have no appreciable effect on results of either atmospheric or total immersion tests. Solution-treated material corrodes faster than that in other conditions when totally immersed, regardless of iron content, but not in the atmosphere.

METAL FAILURE

The Corrosion-Fatigue Properties of Some Hard Lead Alloys in Sulfuric Acid. D. J. MACK (Univ. of Tenn.) Paper in part-fulfillment of PhD. requirements, A. S. T. M. 1945, Preprint 32, 22 pp.

Fatigue properties of pure lead, tellurium-lead, 1 percent antimonial lead and commercial storage battery lead were determined on a rotating beam machine of the cantilever type at 1785 rpm. The endurance limits of these four materials were determined: (a), in air, specimens being coated with vaseline; (b), in 38 percent sulfuric acid, applied to specimens by dripping; and (c), in air after specimens had been previously corroded in sulfuric acid while stress free. Endurance limits obtained in (a) checked many of those already reported in the literature, all tested at high speed. It was concluded that the corrosion-fatigue resistance of these alloys in sulfuric acid is a running balance between fatigue strength and corrosion resistance. There was good correlation between the results in (a) and (c) but not in (b), showing that if the corrosion and cyclic stress occur simultaneously, damage is to be expected. The mechanism of corrosion-fatigue action in lead and lead alloys in sulfuric acid was examined. It is believed that lead sulfate film is opened up over the underlying grain boundaries by elastic deformation of the grains and by the tendency of the lead to recrystallize, allowing the acid to attack the grain boundary creating a notch.

Theory of Stress-Corrosion Cracking of Mild Steel in Nitrate Solution. J. T. WABER, H. J. Longtin, B., Ill. Inst. of Tech., Electrochemical Soc., Preprint 32, **87,** 439 (1945).

Stress-corrosion cracking of mild steel in nitrate solutions is shown to depend on the stress-accelerated age-hardening of the steel. A correlation between cracking times and extent of aging was made, and both the extent of aging after a standard treatment and the rate of cracking after several heat treatments were correlated with the free nitrogen factor. A steel can be made only relatively more, not completely, resistant to stress corrosion cracking. It was possible to crack repeatedly supposedly resistant mild steels. An experimental procedure was evolved to select the test solution and design of specimen. Cracking proceeds rapidly when steels are loaded to stresses slightly less than the yield point but greater than a certain threshhold stress. The acceleration of quench aging of mild steel by elastic stresses was shown. The age-hardening mechanism of stress-corrosion cracking was partially confirmed. The conditions under which cracking occurs do not differ in principle from those necessary to produce caustic embrittlement. Graphs show change of notch impact values, correlation between "free" nitrogen and cracking time, change in Brinnell hardness number vs. hours aging at various temperatures. Specimen design is shown, and data of experiments are tabulated.

Report on Stress Corrosion Cracking of Boiler-Plate Steel. JAMES T. WABER, HUGH J. MCDONALD AND BRUCE LONGTIN, Ill. Inst. of Technology, Welding J., **24,** 268s (1945) May.

Original plan of project was threefold: (1), to develop testing methods suitable for producing cracking; (2), to study the influence of such variables as heat treatment, stress level, chemical analysis of the steels, composition and acidity of the corroding solution, etc.; and (3), to study the mechanism of stress-corrosion cracking. Project No. 1 has been completed and the influence of heat treatment and stress level have been investigated. Cracking has been found to be intercrystalline.

Detection of Intercrystalline Corrosion in Aluminum Alloys. S. E. PAVLOV, Zavod, Lab. **10,** 394 (1941), Chem. Zentr., **114,** 563 (1943) (in Russian) J. of the Inst. of Metal and Metall. Abs. **12,** 113 (1945) April.

Micro-examination of etched samples gives less reliable results in the investigation of corrosion attack than does that of finely polished samples. Micro-examination is suitable for the detection of overheating and intercrystalline corrosion in laboratory tests and also in the field if a microscope can be used on the structure. If that is not possible, the surface is washed with benzine or alcohol, treated for 12 to 24 hours with a solution of 30 g./litre sodium chloride and 20 c.c./litre hydrochloric acid, dried, polished, and examined after 2 hours. If intercrystalline cororsion exists, a light efflorescense occurs after 10 to 20 minutes; with strong corrosion, blisters form later, because the solution penetrates through the corroded grain boundaries into the interior.

Cavitation. FRANK N. SPELLER, A. S. T. M. Bull. **133,** 21 (1945).

The main damage from cavitation is due to the rapid and powerful dynamic impacts produced by the sudden collapse of vapor-filled cavities formed in the water as it passes through low-pressure sections of the conduit. However, corrosion, corrosion fatigue, high velocity, and the removal of all protective metal surface films appear to be important factors. Remedies include more favorable setting of the turbines or pumps, injection of air into the water at the proper points, avoidance of rough surface finish and sudden changes of curvature, and use of corrosion-resisting metals such as austenitic stainless steel.

WATER CORROSION

Fundamental Principles. U. R. EVANS, Cambridge University, England, Ind. & Eng. Chem. **37,** 703 (1945) Aug.

The general factors involved in the processes of inhibiting corrosion are discussed. Inhibitors are classified and discussed as anodic and cathodic; anodic inhibitors being those which build up protection by stifling the anodic reaction and cathodic those which stifle the cathodic reactions. Anodic inhibitors are more efficient than cathodic inhibitors although many of them may produce an increase in pitting which may be very serious unless the treatment is adequately controlled. Evans discusses safe and dangerous inhibition systems. This paper is discussed by D. S. McKinney and J. C. Warner, Carnegie Inst. of Technology, and by W. H. J. Vernon and F. Wormwell, Dept. of Scientific and Industrial Research, Teddington, England.

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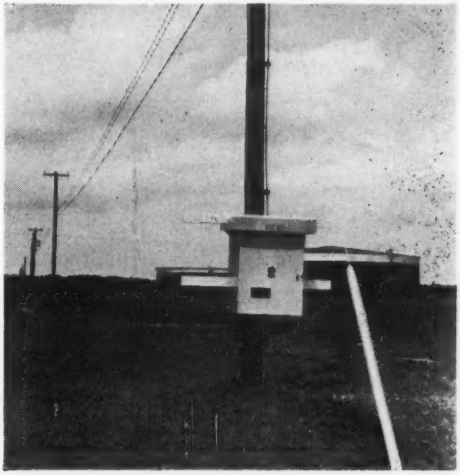

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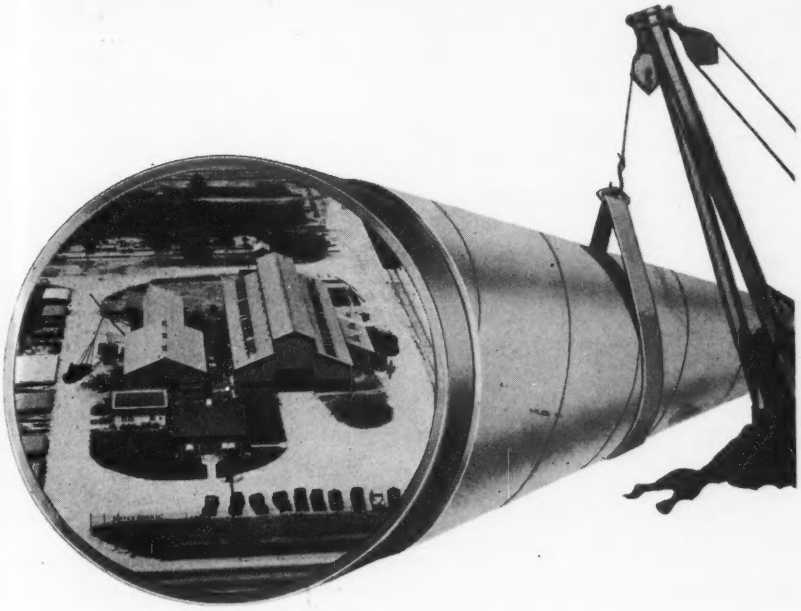

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The facilities of eighty-six strategically-located Graybar warehouses, for fast-action service in bringing together the required equipment and materials.

For further information concerning Electrical Construction materials for protective installations, call or write Graybar, headquarters for "Everything Electrical."

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Index to Advertisers

Allied Chemical & Dye Corp., Barrett Div. ..... Inside Front Cover
American Brass Co. 15
American Cast Iron Pipe Co. 41
American Hot-Dip Galvanizers Association, Inc. 11
Armco Drainage & Metal Products, Inc. .. 17
Brance-Krachy Co., Inc. 37
Crutcher-Rolfs-Cummings ..... Inside Back Cove
Crutcher-Rolfs-Cummings ..... Inside Back Cover
Dearborn Chemical Company 16
Dow Chemical Co., Magnesium Div. 33
Dresser Industries, Inc., Dresser Mfg. Div. 13
Federal Telephone & Radio Corp. 12
General Paint Corp., Hill-Hubbell & Co. Div. 4
Graybar Electric Co. 45
Haering, D. W. & Co. 8
Humble Oil & Refining Co. 43
International Nickel Company, Inc. 5
Jacobs Wind Electric Co., Inc. 43
Johns-Manville 10
Mavor, James E. 41
Mayes Brothers, Inc. 39
Nelson Electric Manufacturing Co. 3
New Jersey Zinc Co. 6
Nox-Rust Corporation 46
Owens-Corning Fiberglas Corp. 9
Pipe Line Service Corp. 35
Shell Oil Co., Inc. 7
Stearns, D. E. ..... Outside Back Cover
Wailes Dove-Hermiston Corp. 14

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THE pipe line equipment we've offered the industry has been developed from scratch by our organization. Never has a single idea been taken from outside sources. Constant research over a period of 20 years has developed CRC pipe line construction equipment that amounts to one of the major steps in the progress of the industry we exclusively serve.

CRC

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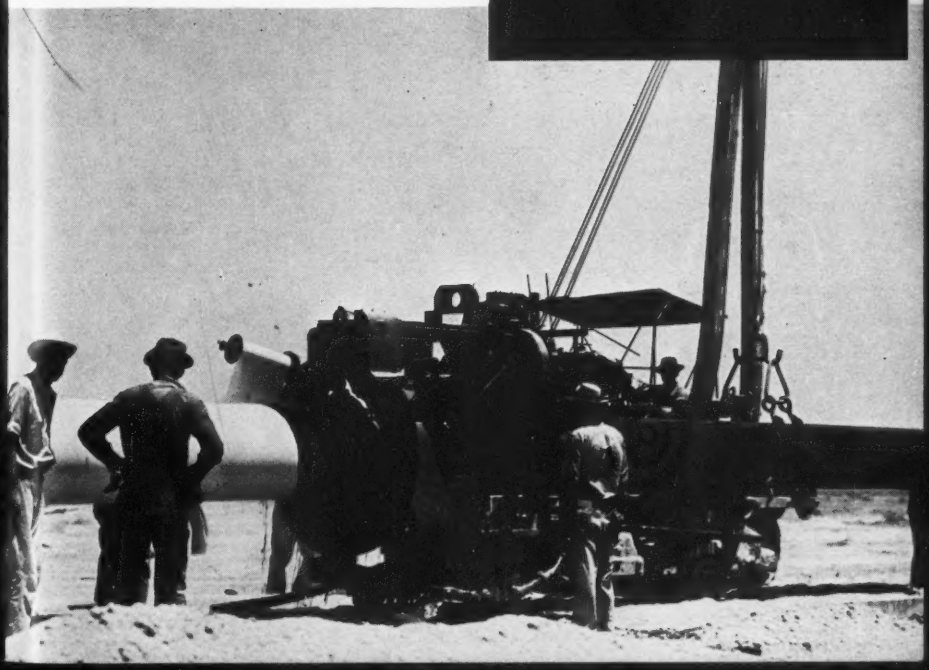

The Rolling Coiled Spring Exploring Electrode is an *exclusive patented* feature of the Stearns Electronic Holiday Detector insuring thorough and uniform application of the inspection voltage to the insulating coating.

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